Federal Aviation Administration – Regulations and Policies
Aviation Rulemaking Advisory Committee

Transport Airplane and Engine Issue Area
Avionics Systems Harmonization Working Group

Task 4 – Warning Caution and Advisory Lights

Task Assignment

[Federal Register: April 23, 2002 (Volume 67, Number 78)]
[Notices]
[Page 19796-19797]
From the Federal Register Online via GPO Access [wais.access.gpo.gov]
[DOCID:fr23ap02-119]

DEPARTMENT OF TRANSPORTATION

Federal Aviation Administration

Aviation Rulemaking Advisory Committee; Transport Airplane and Engine Issues--New Task

AGENCY: Federal Aviation Administration (**FAA**) (DOT).

ACTION: Notice of new task assignment for the Aviation Rulemaking Advisory Committee (ARAC).

SUMMARY: The **FAA** assigned four new tasks to the Aviation Rulemaking Advisory Committee to develop recommendations that will broaden current regulations and advisory material to include state-of-the-art flightdeck displays and new technologies to aid flight crewmembers in decision making. This notice is to inform the public of this ARAC activity.

FOR FURTHER INFORMATION CONTACT: Mike Kaszycki, Federal Aviation Administration, Northwest Mountain Region Headquarters, 1601 Lind Avenue, SW., Renton, Washington, 98055; telephone: 425-227-2137; fax: 425-277-1320; e-mail: mike.kaszycki@**faa**.gov.

SUPPLEMENTARY INFORMATION:

Background

Problem

Title 14 Code of Federal Regulations Sec. 25.1322 describes standards for the color of warning, caution, advisory, and other message lights that are installed as annunciation displays in the flightdeck. It addresses visual alerting cues only in the form of colored lights installed in the flightdeck. The regulation became effective February 1 1977 (Amendment No. 25-38, 41 FR 44567, December 20, 1976) and has never been amended. It does not consider the use of corresponding aural tones/voice and prioritization of multiple alerts that may occur at the same time. Nor, does it consider new technologies, other than colored lights, that may be more effective in aiding the flightcrew in decision making. Further, Sec. 25.1322 is outdated, does not address safety concerns associated with today's display systems, and has resulted in additional work for applicants when showing compliance, and for the **FAA** when addressing new flightdeck designs and the latest display technologies via special conditions and issue papers.

Advisory Circular (AC) 25-11, Transport Category Airplane Electronic Display Systems, contains guidance for demonstrating compliance with Sec. 25.1322. The scope of the AC, which was published July 16, 1987, is limited and pertains strictly to cathode ray tube (CRT) based electronic display systems used for guidance, control, or decision making by the flightcrew. The guidance is clearly outdated in view of the computer-based and other advanced technological instruments used in transport category airplanes today.

Any rule or advisory circulars that results from this action would affect all new transport airplanes that are certified to part 25/Joint Aviation Requirements 25 (JAR-25). Both the **FAA** and industry agree that Sec. 25.1322 is not appropriate for the current or future flightdeck design and the technologies associated with visual and aural annunciations to the flightcrew. This outdated regulation results in a potentially significant effect on airplane design, product design and technical standard orders, system integration, airplane type certifications and supplemental type certifications, costs associated with certifications, and flightcrew operation on airplane safety.

Tasking Statement

For the problem described above, the **FAA** tasked the ARAC \1\ to:

1. Review and recommend revisions Sec. 25.1322 that are necessary to bring the safety standards up-to-date; make the standards more appropriate for addressing current and future flightdeck design and technologies associated with visual and aural annunciation; and address prioritization of multiple alerts that may occur at the same time. At a minimum, the recommendations must consider airworthiness, safety, cost, recent certification and fleet experience, and harmonization of JAR 25.1322.

\1\ In 1992, the **FAA** established the ARAC to provide advice and recommendations to the **FAA** Administrator on the agency's rulemaking activities with respect to aviation-related issues. This includes obtaining advice and recommendations on the **FAA**'s commitments to harmonize Title 14 of the Code of Federal Regulations (14 CFR) with its partners in Europe and Canada.

----

2. Review the existing Advisory Circular Joint (ACJ) 25.1322 and determine if a harmonized AC 25.1322 should be developed.

3. Identify any rules or advisory circulars that may conflict with the revised rule to determine if changes should be developed and address the proposed changes to Secs. 25.1309 and 25.1329 that pertain to alerting.

4. Recommend revisions to AC 25-11 and ACJ 25-11.

a. Review AC 25-11 and ACJ 25-11 to develop harmonized advisory material. The harmonized guidance material may be significantly different from the existing material, but it must not conflict with the harmonized Sec. 25.1322 standard.

b. Coordinate with other harmonization working groups in revising the advisory material. The Human Factors HWG is currently working a similar activity and should be consulted to ensure that any revised material has appropriate input and influence from the human factors discipline. Review and revision of the powerplant-related sections of AC 25-11 should be delegated to the Powerplant Installation HWG. The Flight Test HWG should review the flight test related sections.

c. Prepare a ``user needs analysis'' that addresses some unique requirements that are not fully met by the current guidance. (For example, manufacturers and installers of liquid crystal display based systems are considered ``users'' whose needs may not currently be met.)

d. Review other advisory circulars (such as AC's/ACJ's for various systems) and other industry documents to understand their relevance to AC 25-11. Additionally, recent industry activities have produced materials (for example, Aviation Recommended Practices) that may be useful in developing the harmonized AC.

e. Recommend a format of the advisory circulars that can accommodate future changes. The current AC/ACJ format is not conducive to additions as new systems are developed, new functions are identified, and new technologies are employed. The revised harmonized AC/ACJ should be formatted to accommodate future changes.

For each task, ARAC is to review airworthiness, safety, cost, and other relevant factors, including recent certification and fleet experience. ARAC will submit a report to the **FAA** (format and content to be determined by the **FAA**) that recommends revisions to the regulation, including cost estimates, and outlines the information and background for the advisory circulars.

If a notice of proposed rulemaking or notices of proposed advisory circulars are published for public comment as a result of the recommendations, ARAC may be further asked to review all comments received and provide the **FAA** with a recommendation for disposition of public comments for each project.

[[Page 19797]]

Schedule: The report and draft advisory circular is to be completed no later than 24 months after the **FAA** publishes the tasks in the Federal Register.

ARAC Acceptance of Tasks

ARAC accepted and assigned the task to the Avionics Systems Harmonization Working Group. The working group serves as staff to ARAC and assists in the analysis of the assigned task. ARAC must review and approve each working group's recommendations. If ARAC accepts the working group's recommendations, it will forward them to the **FAA**. Recommendations that are received from ARAC will be submitted to the agency's Rulemaking Management Council to address the availability of resources and prioritization.

Working Group Activity

The Avionics System Harmonization Working Group must comply with the procedures adopted by ARAC. As part of the procedures, the working group must:

1. Recommend a work plan for completing each task, including the rationale supporting such a plan for consideration at the October 15-16, 2002, meeting of the ARAC on transport airplane and engine issues.

2. Give a detailed conceptual presentation of the proposed recommendations before proceeding with the work stated in item 3.

3. Draft the appropriate documents and required analyses and/or any

other related materials or documents.
4. Provide a status report at each ARAC meeting on transport airplane and engine issues.

Participation in the Working Group

The Avionics Systems Harmonization Working Group is composed of technical experts having an interest in the assigned tasks. A working group member need not be a representative or a member of the full committee.

An individual who has expertise in the subject matter and wishes to become a member of the working group should write to the person listed under the caption FOR FURTHER INFORMATION CONTACT expressing that desire, describing his or her interest in the task, and stating the expertise he or she would bring to the working group. All requests to participate must be received no later than (1 month after publication of the tasking statement). The requests will be reviewed by the assistant chair, the assistant executive director, and the working group co-chairs. Individuals will be advised whether their request can be accommodated.

Individuals chosen for membership on the working group must represent their aviation community segment and actively participate in the working group (e.g., attend all meetings, provide written comments when requested to do so, etc.). They must devote the resources necessary to support the working group in meeting any assigned deadlines. Members are expected to keep their management chain and those they may represent advised of working group activities and decisions to ensure the proposed technical solutions do not conflict with their sponsoring organization's position when the subject being negotiated is presented to ARAC for approval.

Once the working group has begun deliberations, members will not be added or substituted without the approval of the assistant chair, the assistant executive director, and the working group co-chairs.

The Secretary of Transportation determined that the formation and use of the ARAC is necessary and in the public interest in connection with the performance of duties imposed on the **FAA** by law.

Meetings of the ARAC will be open to the public. Meetings of the Avionics Systems Harmonization Working Group will not be open to the public, except to the extent that individuals with an interest and expertise are selected to participate. The **FAA** will make no public announcement of working group meetings.

Issued in Washington, DC, on April 11, 2002.
Anthony F. Fazio,
Executive Director, Aviation Rulemaking Advisory Committee.
[FR Doc. 02-9947 Filed 4-22-02; 8:45 am]
BILLING CODE 4910-13-M

Recommendation Letter

Pratt & Whitney
400 Main Street
East Hartford, Connecticut 06108

May 14, 2004

Federal Aviation Administration
800 Independence Avenue SW
Washington, D.C. 20591

Attention: Mr. Nicholas Sabatini, Associate Administrator for Regulation and Certification

Subject: ARAC Recommendations, 14 CFR 25.1322

Reference: ARAC Tasking, Federal Register, dated April 23, 2002

Dear Nick,

The Transport Airplane and Engine Issues Group is pleased to submit the following as a recommendation to the FAA in accordance with the reference tasking. The Avionics Systems Harmonization Working Group has prepared this information.

ASHWG Report – 14 CFR 25.1322

The TAEIG unanimously accepted the ASHWG report. During the discussion, the industry representatives on TAEIG felt that when considering the acceptability of these colors for graphical weather depiction, the potential safety benefits should be considered during the certification process.

Sincerely yours,

Craig R. Bolt

Craig R. Bolt
Assistant Chair, TAEIG
boltcr@pweh.com
(Ph: 860-565-9348/Fax: 860-557-2277)

Copy: Dionne Krebs – FAA-NWR
Mike Kaszycki – FAA-NWR
Alicia Douglas – FAA-Washington, D.C.
Clark Badie - Honeywell

Acknowledgement Letter

SEP 2 0 2004

Mr. Craig R. Bolt
Assistant Chair, Aviation Rulemaking
Advisory Committee
Pratt & Whitney
400 Main Street, Mail Stop 162-14
East Hartford, CT 06108

Dear Mr. Bolt:

This letter acknowledges receipt of several letters that you sent for the Aviation Rulemaking Advisory Committee (ARAC) on Transport Airplane and Engine (TAE) Issues.

Date of Letter	Description of Recommendation	Working Group
01/06/2003	Proposed rule and draft advisory material on bird ingestion capability (§ 33.76)	Engine Harmonization Working Group (HWG)
10/22/2003	Final report and position statements on bird strike requirements (§ 25.631)	General Structures HWG
10/22/2003	Final report and draft advisory material on alternative composite structure material (§ 25.603)	General Structures HWG
05/14/2004	Final report, proposed rule language, and draft advisory material on warning, caution, and advisory alerts installed in the cockpit (§ 25.1322)	Avionics Systems HWG
06/17/2004	Final report and draft advisory material on fire protection of flight controls, engine mounts and other flight structures (§ 25.865)	Loads and Dynamics HWG
06/22/2004	Final report, proposed rule, and draft advisory material on installed systems and equipment for use by the flight crew (§ 25.1302)	Human Factor HWG

I wish to thank the ARAC and the working groups for the resources that industry gave to develop these recommendations. The recommendations from the Avionics Systems HWG, the Human Factor HWG, and the Loads and Dynamics HWG will remain open until these working groups complete a Phase 4 review. The remaining recommendations have been closed, as we consider submittal of the reports as completion of the tasks. All of these recommendations will be placed on the ARAC website at **http://www.faa.gov/avr/arm/arac/index.cfm**.

We will continue to keep you apprised of our efforts on the ARAC recommendations and the rulemaking prioritization at the regular ARAC TAE issues meetings.

Sincerely,

Original Signed By
Margaret Gilligan

Nicholas A. Sabatini
Associate Administrator for Regulation
and Certification

cc: ARM-1/20/200/204/207; AIR-100, ANM-110

ARM-207:JLinsenmeyer:fs:8/12/04:PCDOCS # 21644
Control Nos. 20041855-0; 20041944-0; 20042001-0

Recommendation

ARAC WG Report
FAR/JAR 25.1322 & AC/ACJ 25.1322

1. What is underlying safety issue addressed by the FAR/JAR?
   The rule provides color requirements for warning, caution and advisory lights associated with alerting functions. However, the current rule only addresses "lights" and does not take into consideration the implementations, technology, and associated safety issues with the latest flight deck alerting systems.

   FAR/JAR 25.1322 describes standards for the color of warning, caution, advisory, and other message lights that are installed as annunciation displays in the flight deck. It addresses visual alerting cues only in the form of colored lights installed in the flight deck. The regulation became effective February 1, 1977 (Amendment No. 25-38, 41 FR 44567, December 20, 1976) and has never been amended. It does not consider the use of corresponding aural tones/voice and prioritization of multiple alerts that may occur at the same time. Nor does it consider new technologies, other than colored lights, that may be more effective in aiding the flight crew in decision making. Further, FAR/JAR 25.1322 is outdated, does not address safety concerns associated with today's display systems, and has resulted in additional work for applicants when showing compliance, and for the FAA when addressing new flight deck designs and the latest display technologies via special conditions and issue papers.

2. What are the current FAR and JAR standards?

   Current FAR text:

   If warning, caution, or advisory lights are installed in the cockpit, they must, unless otherwise approved by the Administrator, be--
   (a) Red, for warning lights (lights indicating a hazard which may require immediate corrective action);
   (b) Amber, for caution lights (lights indicating the possible need for future corrective action);
   (c) Green for safe operation lights; and
   (d) Any other color, including white, for lights not described in paragraphs (a) through (c) of this section, provided the color differs sufficiently from the colors prescribed in paragraphs (a) through (c) of this section to avoid possible confusion.

   Current JAR text:

   If warning, caution, or advisory lights are installed in the cockpit, they must, unless otherwise approved by the Authority, be -
   (a) Red, for warning lights (lights indicating a hazard which may require immediate corrective action);
   (b) Amber, for caution lights (lights indicating the possible need for future corrective action);
   (c) Green, for safe operation lights; and
   (d) Any other colour, including white, for lights not described in sub-paragraphs (a) to (c) of this paragraph, provided the colour differs sufficiently from the colours prescribed in sub-paragraphs (a) to (c) of this paragraph to avoid possible confusion.

3. What are the differences in the standards and what do these differences result in?:
   There are no differences in the standards. There is a related AMJ, but no AC.

4. What, if any, are the differences in the means of compliance?
   Specific means of compliance to JAR 25.1322 are provided in the associated AMJ.
   No specific means of compliance exists for FAR 25.1322.

5. What is the proposed action?
The FAR 25 and JAR 25 and their associated guidance material have been identified as lacking content and guidance commensurate with the state-of-the-art. Therefore, a new FAR/JAR 25.1322 will be written to address current or future flight deck design and the technologies associated with flight crew alerting. The existing AMJ will be reviewed and harmonized advisory material will be generated.

6. What should the harmonized standard be?
A new FAR/JAR 25.1322 and associated AC/AMJ 25.1322. (See Attachment and file Draft AC25.1322 DC Meeting 1003_rev a)

7. How does this proposed standard address the underlying safety issue (identified under #1)?
The new standard will address the requirements for crew alerting systems and provide content and guidance that is commensurate with the state-of-the-art flight deck alerting systems.

8. Relative to the current FAR, does the proposed standard increase, decrease, or maintain the same level of safety?
The level of safety will be increased by providing new standards and guidance material that is commensurate with the state-of-the-art and crew alerting, and by providing guidance for other Part 25 regulations that require the use of alerting.

9. Relative to current industry practice, does the proposed standard increase, decrease, or maintain the same level of safety?
The new standards and guidance material supports current industry practice and will increase the level of safety.

10. What other options have been considered and why were they not selected?:
The group initially thought of adopting the JAR and associated AMJ. However, this was still deemed insufficient for today's flight deck alerting systems. The level of effort to rewrite the rule was significant, and each sub-paragraph was reviewed and many options were considered. In addition, the Human Factors Harmonization Working Group provided additional options for consideration. The group has modified wording in the draft AC/ACJ to address the means of compliance to sub paragraph e) in the rule.

11. Who would be affected by the proposed change? The (Part 25) aviation industry in general including aircraft manufacturers, aircraft operators, avionics manufacturers, and regulators, if they are not already practicing the essence of these standards. There may be indirect effect to manufacturers that wish to develop products and systems that are intended to cross part 23/25/27/29 applications.

12. To ensure harmonization, what current advisory material (e.g., ACJ, AMJ, AC, policy letters) needs to be included in the rule text or preamble?
AC/AMJ 25-11, and parts of the draft AC/AMJ 25-1322.

13. Is existing FAA advisory material adequate? No. There is no existing FAA advisory material. However, there is an existing AMJ 25.1322 and that document has been revised to incorporate this latest information.

14. How does the proposed standard compare to the current ICAO standard?
There are no applicable ICAO standards.

15. Does the proposed standard affect other HWGs? Yes. We have coordinated with the working groups responsible for Human Factors (25.1301(e)), Propulsion and Safety (25.1309). We have also coordinated with other industry groups such as the RTCA SC-195 committee.

16. What is the cost impact of complying with the proposed standard?

    For those manufacturers that are already in compliance / already practicing. Harmonization of 25.1322 and the associated guidance material will significantly reduce certification costs, thereby improving the allocation of limited resources.

    For those manufacturers that are not in compliance/not already practicing, there may be additional costs to comply with the new rule.

    There is a general potential problem with the change process, if this revised rule is used for new applications of existing products and systems, or if this revised rule is applied to any modifications to existing products and systems.

17. Does the HWG want to review the draft NPRM at "Phase 4" prior to publication in the Federal Register?

    Yes

18. In light of the information provided in this report, does the HWG consider that the "Fast Track" process is appropriate for this rulemaking project, or is the project too complex or controversial for the Fast Track Process?

    Yes, it is appropriate for the "Fast Track" process. The group identified an issue regarding sub paragraph (e) in the draft rule that caused controversy. The group resolved this to our satisfaction by revising both the regulation and advisory material, based on comments received from the RTCA SC-195 committee and from within group membership.

    The AVHWG will also update AC/AMJ 25-11 to cover the broad scope of the use of colors in the flight deck.

FAR/JAR 25.1322 Flight Crew Alerting

(a) When flight crew alerts are provided they must:

1) Provide timely attention-getting cues through at least two different senses by combination of aural, visual, or tactile indications, for crew alerts requiring immediate flight crew awareness.
2) Provide the flight crew with the information needed to identify the alert and determine correct action, if any.
3) Be readily and easily detectable and intelligible by the flight crew under all foreseeable operating conditions including conditions where multiple alerts are provided.

(b) Alerts must conform to the following prioritization hierarchy based upon urgency of flight crew awareness and urgency of flight crew response.

1) Warning: For conditions that require immediate flight crew awareness and immediate flight crew response. If warnings are time critical to maintain the immediate safe operation of the airplane, they must be prioritized higher than other warnings.
2) Caution: For conditions that require immediate flight crew awareness and subsequent flight crew response.
3) Advisory: For conditions that require flight crew awareness and may require subsequent flight crew response.

(c) Alert presentation means must be designed to minimize nuisance effects. In particular a crew alerting system must:

1) Permit each occurrence of attention getting cues, if provided, to be acknowledged and suppressed unless they are otherwise required to be continuous.
2) Prevent the presentation of an alert that is inappropriate or unnecessary for the particular phase of operation.
3) Remove the presentation of the alert when the condition no longer exists
4) Provide a means to suppress an attention getting component of an alert caused by a failure of the alerting system, and/or the sensors, which interfere with the flight crew's ability to safely operate the aircraft. This means must not be readily available to the flight crew such that it could be operated inadvertently, or by habitual reflexive action. In this case, there must be a clear and unmistakable annunciation to the flight crew that the alert has been suppressed.

(d) Alerts must conform to the following color convention for visual alert indications:

1) Red for Warning alert indications.
2) Amber/yellow for Caution alert indications.
3) Any color except red or green for Advisory alert indications.

(e) The colors red and amber/yellow are normally reserved for alerting functions. The use of these colors for functions other than crew alerting must be limited and must not adversely affect crew alerting.

Final Version AC/ACJ 25.1322 – **Updated April 2004 in London.**
Flight Crew Alerting

Table of Contents

PURPOSE

This advisory circular (AC) provides guidance for the design and approval of flight crew Alerting Functions installed in transport category airplanes.

SCOPE

This advisory circular applies to the installation, integration, and certification of flight deck alerting systems, whether they are integrated or not. That is, it applies to individual aircraft systems that provide alerts that may or may not be integrated with a central alerting system, as well as systems whose primary function is alerting, such as a central alerting system. The alerting system may be approved as part of a TC/STC/ATC/ASTC.

This AC provides guidance as to what is considered an alert. However, what should be alerted to the flight crew is dependent on the specific design and overall flight deck philosophy. For example, the failure of a single sensor in a multi-sensor system in some cases may not necessarily result in an alert condition that the pilot needs to be aware of. However, for a single sensor system such a failure would certainly result in alert. Thus, the applicant should discuss the overall flight deck design and alerting philosophy with the Authority when determining what should be alerted to the flight crew. Any system that provides an alert should follow the guidance in this AC.

Like all AC material, this AC is not mandatory and does not constitute a regulation. It is issued to provide guidance and to outline a method of compliance with rules and in particular 25.1322.

RELATED REGULATIONS

The following list of regulations describe requirements for flight crew alerting for which this advisory circular provides guidance.

CFR/JAR 25.207	Stall warning
CFR/JAR 25.253(a)(2)	High-speed characteristics
CFR/JAR 25.672(a)	Stability Augmentation…
CFR/JAR 25.679(a)	Control system gust locks
CFR/JAR 25.703	Takeoff warning system
CFR/JAR 25.729(e)	Retracting mechanism
CFR/JAR 25.783(e)	Doors
CFR/JAR 25.812(f)(2)	Emergency lighting
CFR/JAR 25.819(c)	Lower deck service compartments
CFR/JAR 25.841(b)(6)	Pressurized cabins
CFR/JAR 25.854(a)	Lavatory fire protection
CFR/JAR 25.857(b)(3)	Cargo compartment classification
CFR/JAR 25.857(c)(1)	Cargo compartment classification
CFR/JAR 25.857(e)(2)	Cargo compartment classification
CFR/JAR 25.859(e)(3)	Combustion heater fire protection
CFR/JAR 25.863(c)	Flammable fluid fire protection
CFR/JAR 25.1019(a)(5)	Oil strainer or filter
CFR/JAR 25.1165(g)	Engine ignition systems
CFR/JAR 25.1203(b)(2)	
CFR/JAR 25.1203(b)(3)	Fire-detector system
CFR/JAR 25.1203(f)(1)	Fire-detector system
CFR/JAR 25.1303(c)(1)	Flight and navigation instruments
CFR/JAR 25.1305(a)(1)	
CFR/JAR 25.1305(a)(5)	Powerplant instruments
CFR/JAR 25.1305(c)(7)	Powerplant instruments
CFR/JAR 25.1309(c)	Equipment, systems, and installations
CFR/JAR 25.1309(d)(4)	Equipment, systems, and installations
CFR/JAR 25.1322	Warning, caution, and advisory lights
CFR/JAR 25.1326	Pitot heat indication systems
CFR/JAR 25.1331(a)(3)	Instruments using a power supply
CFR/JAR 25.1353(c)(6)(ii)	Electrical equipment and installations
CFR/JAR 25.1419(c)	Ice protection
CFR/JAR 25.1517(3)	Rough air speed, V_{RA}
CFR/JAR 25, Appendix I Section 25.6	Installation of an Automatic Takeoff Thrust Control System (ATTCS) Powerplant Instruments
CFR/JAR 33.71(b)(6)	Lubrication system.
CFR/JAR 91.219	Altitude alerting system or device: Turbojet powered civil airplanes
CFR/JAR 91.221	Traffic alert and collision avoidance system equipment and use

CFR/JAR 91.223	Terrain awareness and warning system
CFR/JAR 91.603	Aural speed warning device
CFR/JAR 91, Appendix A Section 91.2(b)(1)	Required instruments and equipment
CFR/JAR, Appendix G Section 91.2(c)(3) (RVSM) Airspace - Aircraft approval	Operations in Reduced Vertical Separation Minimum
CFR/JAR 91, Appendix G Section 91.3(c)(6)	Instruments and Equipment Approval
CFR/JAR 121.221(c)(1)	Fire precautions
CFR/JAR 121.221(d)(1)	Fire precautions
14 CFR 121.221(f)(2)	Fire precautions
14 CFR 121.289	Landing gear: Aural warning device.
14 CFR 121.307(k)	Engine instruments
14 CFR 121.308(a)	Lavatory fire protection.
14 CFR 121.319(b)	Crewmember interphone system
14 CFR 121.354	Terrain awareness and warning system
14 CFR 121.356(b)	Traffic alert and collision avoidance system
CFR/JAR 121.358	Low-altitude windshear system equipment requirements
CFR/JAR 121.360(a)	
CFR/JAR 121.360(e)	
CFR/JAR 121.360(f)	Ground proximity warning-glide slope deviation alerting system
CFR/JAR 125.187	Landing gear: Aural warning device.
CFR/JAR 125.205(d)	Equipment requirements: Airplanes under IFR.
CFR/JAR 125.221(a)	Traffic alert and collision avoidance system
CFR/JAR 135.150(b)(7)	Public address and crewmember interphone system
14 CFR 135.153(a)	Ground proximity warning system.
14 CFR 135.154	Terrain awareness and warning system
14 CFR 135.163(d)	Equipment requirements: Aircraft carrying passengers under IFR.
14 CFR 135.180(a)	Traffic alert and collision avoidance system
14 CFR 135, Appendix A Section A135.1	Additional Airworthiness Standards for 10 or More Passenger Airplanes

RELATED DOCUMENTS

Only those sets of materials that were used as reference for this AC/AMJ are listed.

1.a Federal Aviation Administration Documents.

(1) Report DOT/FAA/RD-81/38, II, Aircraft Alerting Systems Standardization Study, Volume II, Aircraft Alerting Systems Design Guidelines. This document can be obtained from the National Technical Information Service, Springfield, Virginia 22166

(2) AC 25-11, Transport Category Airplane Electronic Display Systems 7/16/87

(3) Report DOT/FAA/CT-96/1 - GAMA Report No 10, "Recommended Guidelines for Part 23 Cockpit/Flight Deck Design" (September 2000), Section 4, Definitions, Primary Field of View.

(4) AC 25-23 TAWS Terrain Awareness and Warning Systems

(5) AC 25-1309-1A System Design and Analysis
(6) TSO C-151a, Terrain Awareness and Warning Systems
(7) AC 25.1523-1, Minimum Flight Crew & Workload

1.b JAA Documents.

(1) AMJ 25.1322, Alerting Systems, dated 12 April, 1991
(2) AMJ 25.1309 System Design and Analysis
(3) AMJ 25-11, Electronic Display Systems

(4) Patterson, R.D. (1982). *Guidelines for Auditory Warning Systems on Civil Aircraft.* Cheltenham, England: Civil Aviation Authority paper 82017.

1.c Industry Documents.

1. Edworthy, J. and Adams, A. (1996). Warning Design: A Research Perspective. Bristol, PA: Taylor & Francis.

2. Kuchar, J.K. (1996). Methodology for alerting-system performance evaluation. *Journal of Guidance, Control, and Dynamics. 19, 438-444.*

3. Parasuraman, R., & Riley, V. (1997). Human and Automation: use, misuse, disuse, abuse. *Human Factors, 39,* 216-229.

4. Satchell, P. (1993). *Cockpit monitoring and alerting systems.* Aldershot, England: Ashgate.

5. SAE ARP 4033 (Pilot-System Integration), August 1995

BACKGROUND

In the past airplanes have been designed with discrete lights for the alerting function. Now the alerting functions can be integrated with other systems, including electronic display systems, and aural warning or tone generation systems. This AC addresses the aspects of integration including prioritization, commonality between types of alerts, competing simultaneous aural and visual alerts, correlation of aural and visual alerts, potential inhibiting of alerts, and the increased possibility of false or nuisance alerts.

FAR/JAR Part 25 Regulations and advisory material often provide references to an alert, such as a warning, to provide awareness of a certain condition that is relevant to the applied rule. Many of these rules were written without recognition of a consistent flight deck alerting philosophy, and may use the term “warning” in a generic sense. This AC/ACJ does not intend to conflict with or replace the intent of those rules, but it is meant to provide standardization of crew alerting terminology that may be used in the development of consistent regulations and advisory material, and consistency to show compliance to existing rules.

DEFINITIONS

Definitions are written to support the content of this AC and its associated rule. Other regulations may use terms such as “warning” in a manner that is not necessarily consistent with the definitions below. However, the intent of this section is to facilitate standardization of these terms.

Advisory
The level of alert for conditions that require flight crew awareness and may require subsequent flight crew response

Alert

A generic term used to describe a flight deck indication meant to attract the attention of and identify to the flight crew a non-normal operational or airplane system condition. Warnings, Cautions, and Advisories are considered to be alerts.

Alert Inhibit
Application of specific logic to prevent the presentation of the alert.

Alert Message
A visual alert comprised of text, usually presented on a flight deck display.

Alerting Function
The aircraft function that provides alerts to the flight crew for non-normal operational or airplane system conditions. This includes Warning, Caution and Advisory information.

Alerting Philosophy
The principles, guidance and rules for implementing alerting functions within a flight deck. These typically consider:

- The reason for implementing an alert
- The level of alert required for a given condition
- The characteristics of each specific alert
- Integration of multiple alerts

Attention Getting Cues
Perceptual signals (visual, auditory or tactile/haptic) designed to attract the flight crew's attention in order to obtain the immediate awareness that an alert condition exists.

Caution
The level of alert for conditions that require immediate flight crew awareness and subsequent flight crew response.

Collector Message
An alert message that replaces two or more related alert messages that do not share a common cause or effect. Example: A Doors alert collector message is displayed when more than one entry, cargo, or service access door is open at the same time.

Communication message
A type of message whose initiating conditions are caused by incoming communications, primarily data link conditions. This type of message is not a crew alert.

(1) **Comm High**: A communication message which requires immediate flight crew awareness and immediate flight crew response. (Note: At this time there are no communication messages defined that require immediate flight crew response.)

(2) **Comm Medium**: An incoming communication message which requires immediate flight crew awareness and subsequent flight crew response.

(3) **Comm Low**: An incoming communication message which requires flight crew awareness and future flight crew response.

False Alert
An incorrect or spurious alert caused by a failure of the alerting system including the sensor.

Failure Flag
One local means of indicating the failure of a displayed parameter.

Flashing
Short term flashing symbols approximately 10 seconds or flash until acknowledge.

Flight Crew Response
The activity accomplished due to the presentation of an alert such as an action, decision, prioritization, search for additional information.

Master Aural Alert
An aural indication used to attract the flight crew's attention that is specific to an alert urgency level (e.g. Warning, Caution)

Master Visual Alert
A visual indication used to attract the flight crew's attention that is specific to an alert urgency level (e.g. Warning, Caution).

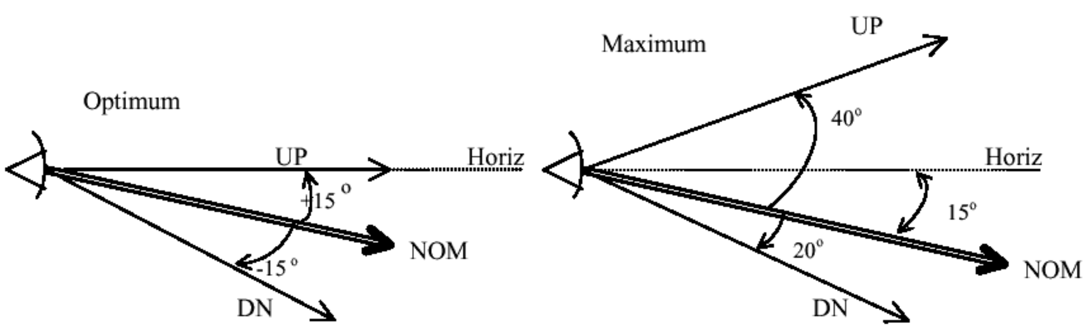
Normal Condition
Any fault-free condition typically experienced in normal flight operations. Operations typically well within the aircraft flight envelope and with routine atmospheric and environmental condition.

Nuisance Alert
An alert generated by a system that is functioning as designed but which is inappropriate or unnecessary for the particular condition.

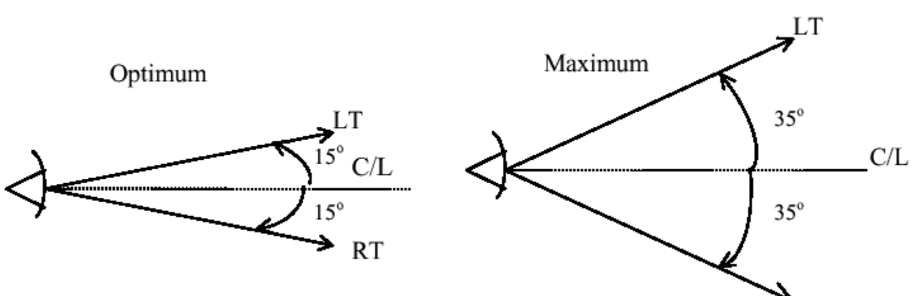
Primary field of view
Primary Field-of-View is based upon the optimum vertical and horizontal visual fields from the design eye reference point that can be accommodated with eye rotation only. The description below provides an example of how this may apply to head-down displays.

With the normal line-of-sight established at 15 degrees below the horizontal plane, the values for the vertical (relative to normal line-of-sight forward of the aircraft) are
+/-15 degrees optimum, with +40 degrees up and -20 degrees down maximum.

For the horizontal visual field (relative to normal line-of-sight forward of the aircraft), the values are +/-15 degrees optimum, and +/-35 degrees maximum. .



Vertical Field of View



Horizontal Field of View

Status
A specific aircraft system condition that is recognized using a visual indication, but does not require an alert and does not require flight crew response. These types of messages are sometimes used to determine airplane dispatch capability for subsequent flights.

Tactile/haptic Information
Indication means where the stimulus is via physical touch, force feedback or vibration (e.g. stick shaker).

Time-Critical Warning
A subset of warning. The highest level of warning for conditions that require immediate flight crew response, to maintain the immediate safe operation of the airplane.Examples of Time-Critical warnings are:

- Predictive and Reactive Windshear Warnings
- Terrain Awareness Warnings (TAWS)
- TCAS Resolution Advisory
- Overspeed Warnings
- Low Energy Warnings

Umbrella Message
An alert message that is presented in lieu of two or more alert messages that share a common cause. Example: A single Engine Shutdown message in lieu of the multiple messages for electrical generator, generator drive, hydraulic pump and bleed air messages which would otherwise have been displayed.

Unique Tones (Unique Sounds)
An aural indication that is dedicated to specific alerts. (e.g. fire bell, overspeed)

Visual Alert Information
A visual indication that presents the flight crew with data on the exact nature of the alerting situation. For advisory level alerts, it also provides the awareness.

Voice Information
Means for informing the flight crew of the nature of a specific condition.

Warning
The level of alert for conditions that require immediate flight crew awareness and immediate flight crew response.

GENERAL

The purpose for alerting functions on airplanes is to get the attention of the flight crew, and inform the flight crew of specific airplane system conditions and certain operational events that require their awareness. The ability of the alerting function to accomplish its purpose is effected not only by the alert presentation itself, but also by the sensed condition and information processing for which the alert presentation was initiated. The alert presentation, condition sensing and information processing for the alert should all be designed to support the purpose of the alerting function.

Only airplane system conditions and operational events that require flight crew awareness to support a flight crew response should cause an alert. Conditions and events that do not require flight crew awareness should not cause an alert.

For all alerts which are presented to the flight crew, the action or accommodation for that alert must be either intuitive or a specific procedure must be provided to assist the flight crew in accomplishing corrective or compensatory action. Appropriate flight crew action for flight crew alerts are normally defined by airplane procedures (ex: in checklists), and are trained as part of a flight crew training curriculum or considered basic airmanship.

The presentation of all alerting signals should be accomplished using a consistent alerting philosophy.

1.d Alerting Presentation Elements

Alerting system presentation elements typically include:

- Master Visual Alerts
- Visual Alert Information
- Master Aural Alerts
- Voice Information
- Unique Tones (Unique Sounds)
- Tactile/haptic Information
- Failure Flag

Logic should be incorporated to ensure that the alerting system components are coordinated and provide the proper alert presentation format for each urgency level. For example, the onset of the master visual alert should occur simultaneously with the onset of the master aural alert.

When practical, the voice information message should be identical to the alphanumeric message presented on the visual information display, but at a minimum the voice and alphanumeric messages should be compatible and readily understandable.

Colors used for master caution and master warning should match colors for their respective caution and warning visual alerts.

To maintain the effectiveness of voice alerting, the use of voice should be minimized. To maintain the effectiveness of the visual alerting, consistent use of the colors red and amber/yellow must be implemented throughout the flight deck.

Failure flags and exceedances do not necessarily need to meet the requirements 25.1322(a)(1). For example, failure flags on primary flight displays have been shown to have sufficient attention getting characteristics and thus do not necessarily satisfy all of the requirements for crew alerts, such as providing attention-getting cues through at least two different senses.

1.e Functional Components for each type of Alert

(1) Warning:

The alerting system functional components used to accomplish the alerting and informing functions for warnings should include:

- Master Visual Alert, AND
- Visual Information, AND
- Master Aural Alert, or
  Voice Information or unique tone
  Note: Voice information may be preceded by a master aural alert

It is recognized that in a limited number of cases a master visual and master aural alert may not be required. For example, visual information presented in the pilot's primary forward field of view may be acceptable in place of a master visual alert if it provides sufficient attention-getting characteristics. Exceptions must be evaluated on a case by case basis.

The immediacy of pilot response required for some warning conditions may not be supported by use of the alerting system components described above. Examples of such warning conditions are reactive windshear warning and ground proximity warning. These are typically called “time-critical warnings.”

The alerting system components used for indicating these kinds of conditions must support immediate pilot awareness of the specific condition without further reference to other indications in the flight deck.

The alerting system functional components used to accomplish the alerting and informing functions for time-critical warnings should include:

- Unique voice information and/or unique tone for each condition, AND
- Unique visual alert information in both pilots primary forward field of view for each condition.

Since, for time-critical warnings, it is expected that the unique visual alert information and the unique voice information or unique tone meets the attention-getting requirements for the condition, then the use of a master visual alert is not required. However, if the master visual alert is used, it should be used to aid in the overall attention-getting characteristics and to obtain the desired flight crew response and should not distract the flight crew from the time-critical condition.

2) Caution

The alerting system functional components used to accomplish the alerting and informing functions for cautions should include:

- Master Visual Alert, AND
- Visual Information, AND
- Master Aural Alert, or
  Voice Information or unique tone
  Note: Voice information may be preceded by a master aural alert

It is recognized that in a limited number of cases a master visual and master aural alert may not be required. For example, visual information presented in the pilot’s primary forward field of view may be acceptable in place of a master visual alert if it provides sufficient attention-getting characteristics. Exceptions must be evaluated on a case by case basis.

Some caution alerts are related to conditions that are precursors to potential time-critical warning conditions. In these cases, the alerting system components associated with the caution should be consistent with the components for related time-critical warning.

For example, a TCAS II Traffic condition, which can be a precursor to a TCAS II Resolution Advisory condition, may not have an associated Master Caution and is acceptable because the TCAS Traffic voice information alone provides the characteristic of a caution.

3) Advisory

The alerting system functional components used to accomplish the alerting and informing functions for advisories should include:

- Visual Information - Advisory information may be located in an area where the flight crew is expected to periodically scan for information

  Note: Advisory information does not require immediate flight crew awareness and therefore does not require an attention getting (master) visual or aural feature

Aural or visual information such as maintenance messages, information messages, and other status messages associated with conditions that do not require an alert may be presented to the flight crew, but the presentation of this information should not interfere with the alerting function or its use.

1.f Alerting System Reliability and Integrity

The alerting system should be designed to avoid false and nuisance alerts while providing reliable alerts to the flight crew when needed.

For establishing compliance of the alerting system with 25.1309, both the failure to operate when required and false operation should be considered.

When applying the 25.1309 process to a particular system or function that has an associated flight crew alert, both the failure of the system/function and a failure of its associated alert should be assessed. This should include assessing the effect of a single (common mode) failure that could cause the loss or failure of a system function and the loss of any associated alerting function.

When assessing crew alerting system compliance to 25.1309, particular attention should be paid to the following:

- Availability of the crew alerting function as a common point to several systems: although the individual assessment of not presenting an alert for a given system when required may lead to a specific consequence, the impact of a larger or a complete failure of the crew alerting function may lead to a more severe consequence, and should be assessed.
- Integrity of the alerting system driving the crew's confidence: since the individual assessment of a false or nuisance alert for a given system may lead to a specific consequence, the impact of frequent false or nuisance alerts increases the flight crew's workload, reduces the flight crew's confidence in the alerting system, and affects their reaction in case of a real alert.

  Existing implementations have shown that design of crew alerting systems as an essential system satisfy the two points above, but do not replace the need to show compliance with 25.1309.

Management of AlertS

1.g Prioritization

The objective of prioritization is to provide the most urgent alert to the flight crew.

(1) General Guidelines
A prioritization scheme should be established for all alerts presented throughout the flight deck. Prioritization within each category (Warning, Caution, Advisory) may also be necessary. For example, AC 25-23 (TAWS) identifies situations where prioritization within alert categories is necessary. The prioritization scheme, as well as the rationale for prioritization should be documented and evaluated.

Documentation should include the results of analysis that shows that any alerts that are delayed or inhibited as the result of the prioritization scheme do not adversely impact safety.

(2) Multiple Aural Alerts

Aural alerts should be prioritized so that only one aural alert is presented at a time. If more than one aural alert is presented at a time, each should be clearly distinguishable and intelligible to the flight crew.

Aural alerts must be prioritized based upon urgency of flight crew awareness and urgency of flight crew response. Normally this means Warnings are prioritized first, followed by Cautions and then Advisories. However, there may be a need to prioritize certain alerts of a lower urgency level over alerts of a higher urgency level depending on phase of flight.

When aural alerts are provided, an active alert should be completed before initiating another aural alert. However, active aural alerts may be interrupted by alerts from higher urgency levels if the delay to annunciate the higher priority alert would impact the timely response of the flight crew. If the interrupted alert condition is still active, it may be repeated once the higher urgency alert is completed.

(3) Multiple Visual Alerts

Since two or more visual alerts can occur at the same time, it should be shown that each alert is clearly recognizable to the flight crew.

Visual alert information should be prioritized between levels - Warnings have the highest priority, followed by Cautions and Advisories. When multiple alerts exist in a specific level (ie. multiple Warnings, multiple Cautions), a means for the flight crew to determine the most recent or most urgent alert should be provided. For example, the most recent or highest priority alert may be listed at the top of its own category. This also applies to time-critical alerts that share a dedicated display region.

1.h Alert Inhibits

Alert inhibits are used to prevent the presentation of an alert which is inappropriate or unnecessary for the particular phase of operation.

Alert inhibits are techniques that can be used to resolve prioritization of multiple alert conditions, alert information overload and display clutter. In many circumstances, alert inhibits should be used to prevent additional hazard due to unnecessary flight crew distraction or response (i.e. during takeoff). Alerts may be inhibited automatically by the alerting system, or manually by the flight crew.

The presentation of alert indications should be inhibited under certain conditions where:

- The alert could cause a hazard if the flight crew was distracted by or responded to the alert.
- The alert contributes to display clutter
- The alert provides unnecessary information or awareness of airplane conditions

A number of consequential alerts may be combined into a single higher-level alert

For certain operational conditions not recognized by the alerting system, a means may be provided for the flight crew to inhibit a potential alert that would be expected to occur as the result of the specific operation (e.g. preventing a landing configuration alert for a different landing flap setting). There should be a clear and unmistakable indication that an alert has been manually inhibited by the flight crew, for as long as the inhibit exists.

1.i Clear/Recall of visual alert messages

Clearing visual alert messages from the current display allows the flight crew to remove a potential source of distraction. If a message can be cleared, the system should provide the ability to recall any cleared visual alert message that has been acknowledged where the condition still exists.

There should be a means to identify if alerts are stored (or otherwise not in view), either through a positive indication on the display or through normal flight crew procedures.

1.j Considerations for interface or integration with other systems (ex. Checklist, synoptics, switches, discrete lamps)

All annunciations and indications used to present an alert should be consistent with wording, color, position, or other attributes they may share. Other information displayed in the flight deck associated with the alert condition should facilitate the flight crew's ability to identify the alert condition and determine any correct action.

Information conveyed by the alerting system should lead the flight crew to the correct checklist procedure to facilitate the correct flight crew action. Some alerts may not have an associated checklist procedure because the correct flight crew action is covered by training or basic airmanship (e.g. autopilot disconnect, time critical warnings).

1.k Color standardization

The regulation 25.1322(e) requires that "The colors red and amber/yellow are normally reserved for alerting functions. The use of these colors for functions other than crew alerting must be limited and must not adversely affect crew alerting."

For discrete lights and indicators, the use of red and amber/yellow should be limited exclusively to flight crew alerting functions. The regulation applies to the use of these colors on both alerting systems and non-alerting systems including displays and other indications. Note that a display is not necessarily a single piece of hardware but may include an appropriately partitioned and segregated section/function of a display used exclusively for non-alerting functions. The objective is to limit the use of red and amber/yellow within the flight deck so that these colors always provide an indication of immediacy of response commensurate with the associated hazard.

The use of red and amber/yellow for non-alerting functions may also be appropriate in the flight deck. Authorization can be expected if any of the following guidelines are met:

A. Red may be used for conditions that require immediate flight crew awareness and immediate flight crew response.

B. Amber/yellow may be used for conditions that require immediate flight crew awareness and subsequent flight crew response.

C. If the colors red or amber/yellow are proposed to be used in any other way, the applicant should submit rationale to the authorities for their review and approval including the benefits and the following:

1. The use of red and amber/yellow is appropriate to the task and context of use;
2. The proposed use does not affect the attention getting qualities and does not adversely affect the alerting functions across the flight deck.

NOTE: Graphical depictions of a single weather phenomenon that use color to represent varying intensity or severity may be used only if the use of red and amber/yellow are consistent with paragraphs A, B, or C above.

Examples of already accepted uses of red and amber/yellow related to the paragraphs above include:

- Engine and airframe limit indications;
- Failure flags;
- Electronic checklist elements that correlate to an alert;
- Indications that correlate to an associated alert;
- Weather radar;
- Proximate terrain that correlates to an onboard terrain alerting function.

It is appropriate to use red or amber/yellow failure flags and system indicators for failures/exceedances associated with hazard conditions requiring immediate flight crew awareness. In these cases, the color should be selected based on the immediacy of the flight crew response. In other cases, the use of red and amber/yellow is not appropriate. However, it would not be appropriate to use red flag to indicate the loss of weather radar data, because immediate flight crew response is not required.

1.l Suppression of False Alerts

Pulling circuit breakers should not be the means for the flight crew to suppress an alert.

Certification TEST and evaluation considerations

Because alerting systems or systems with alerting functions vary in complexity, level of integration, number of alerts, and types of alerts, these systems may raise unique certification issues. Thus it is recommended that applicants develop a plan to establish and document how issues will be identified, tracked, and resolved throughout the life cycle of the program. Applicants typically use the Certification Plan for this purpose. For addressing human factors/pilot interface issues applicants may use FAA Policy Memo ANM-99-2, *Guidance for Reviewing Certification Plans to Address Human Factors for Certification of Transport Airplane Flight Decks*. Additionally, the JAA *INT/POL/*25/14 “human factors aspects of flight deck design” provides guidance to evaluate this type of issues, particularly with new or novel systems or functions. A new harmonized AC/ACJ is also being developed.

It is recommended that the applicant document means of compliance with the appropriate regulations, as well as document compliance to and/or divergence from the recommendations in this AC/ACJ. Additionally, rationale should be provided for decisions regarding new or novel features in the design of the alerting system. This will facilitate the certification evaluation in that it enables the Authorities to focus on evaluating areas where the proposed system diverges from the recommended guidance and new or novel features. Thus, areas where the applicant has demonstrated compliance with this AC would typically receive less scrutiny.

The type of certification evaluation will vary depending upon the complexity, degree of integration, and specifics of the alerting system or function proposed. The evaluation should include evaluations of acceptable performance of the intended functions, including the human-machine interface, and acceptability of failure scenarios of the alerting system. The scenarios should reflect the expected operational use of the system. The validation of the performance and integrity aspects will typically be accomplished by a combination of the following methods:

- Analysis

- Laboratory Test
- Simulation
- Flight Test

The certification program should include evaluations of the alerts in isolation and combination throughout appropriate phases of flight and maneuvers, as well as representative environmental and operational conditions. The alerting function as a whole needs to be evaluated in a representative flight deck environment. Representative simulators can be used to accomplish the evaluation of some human factors and workload studies. The level and fidelity of the simulator used should be commensurate with the certification credit being sought and its use should be agreed with the regulatory authority. The assessment of the alerts may be conducted in a lab, simulator or in the actual aircraft. Certain elements of the alerting system may have to be validated in the actual aircraft. The evaluation should be conducted by a representative population of pilots of various background and expertise.

Some specific aspects that should be considered during the evaluation(s):

- Visual, aural, and tactile/haptic aspects of the alert(s)
- Effectiveness of meeting intended function from the human/machine integration, including workload, the potential for flight crew errors and confusion
- Normal and emergency cancellation logic and accessibility of related controls
- Proper integration with other systems, including labelling
- Acceptability of operation during failure modes
- Compatibility with other displays and controls
- Ensure that the alerting system by itself does not issue excessive nuisance alerts nor interfere with other systems
- Inhibition of alerts for specific phases of flight (e.g., takeoff and landing) and for specific airplane configurations (e.g., abnormal flaps and gear)

Evaluations may also be useful to verify the chromaticity (e.g., red looks red, amber looks amber) and discriminability (i.e., colors can be distinguished reliably from each other) of the colors being used, under the expected lighting levels. These evaluations can be affected by the specific display technology being used, so final evaluation with flight quality hardware is sometimes needed

RETROFIT applicability

1.m Purpose

This provides recommendations for the integration of flight crew alerting associated with new aircraft systems into aircraft that currently have a FAR/JAR Part 25 type certificate (legacy aircraft). Many of these systems provide flight deck alerting functionality – This material is provided to give the applicant a means to comply with FAR/JAR 25.1322 without major modification to the existing aircraft flight deck alerting system.

Systems upgrades for legacy aircraft should be compatible with the aircraft flight deck alerting philosophy.

1.n Visual Alerts

(1) Master Warning System. A determination should be made per section 6.3 of this AC/ACJ if the added system warnings will require activation of an aircraft master warning system.

(2) Master Caution System. A determination should be made per section 6.3 of this AC/ACJ if the added system caution will require activation of an aircraft master caution system.

(3) The existing aircraft alerting system may not be able to facilitate the integration of additional aircraft systems and associated alerts due to limitations in the system inputs, incompatible technologies between the aircraft and the system being added, or economic considerations.
   i. The incorporation of an additional master visual function is discouraged. If it is not feasible to interface to the existing master visual function, an additional master visual function may be installed, provided that it does not delay the flight crew's response time for recognizing and responding to the alert.
   ii. New alerts should be integrated into the existing aircraft crew alerting system where possible. If these alerts cannot be integrated, individual annunciators or an additional alerting display system may be added.
   iii. It is permissible for some failure flags not to be integrated in the central alerting system. Thus, a master visual or master aural may not be initiated. The need to
   iv. Conditions that generate failure flags are not necessarily generating an alert.

1.o Aural Alerts

(1) A determination should be made per the guidance of this AC/ACJ, if the added system will require activation of an aural alert.
(2) If possible this new aural alert should be incorporated into the existing aural alerting system, if this is not possible, a separate aural alerting system may be introduced provided that all of the following have been considered
   i. A means is provided to set a prioritization scheme in place between existing aural alerts and the new aural alerts such that each alert is recognized and can be acted upon in the time frame appropriate for the alerting situation.
   ii. Each individual alert can be understood and acted upon. This may require a demonstration of any likely combination of simultaneous alerts.
   iii. The material provided in this AC/ACJ should be utilized in determining the prioritization for the integration of new aural alerts with existing aural alerts

1.p Special Considerations for Head-Up Displays (HUDs)

Although HUDs , when used as Primary Flight Displays (PFDs), are not intended to be classified as integrated caution and warning systems, they may display alerts such as time-critical warnings.

HUDs, when used as PFDs, should provide the equivalent alerting functionality as current head down display (HDD) PFDs. Time critical warnings that require continued flight crew awareness on the PFD should be presented on the HUD (e.g., TCAS, Windshear, and Ground Proximity Warning annunciations). In addition if master alerting indications do not provide sufficient attention to the pilot while using the HUD, the HUD should provide annunciations that inform the pilot of caution and/or warning conditions.

Time-critical warning information that is presented on a Head Up Display may include attributes which are different than those presented on a Head Down Display. For example the use of red on a HUD may not be technically feasible and under certain conditions may detract from the attention-getting characteristics of the associated time-critical warning.

To the extent that current HUDs are single color devices, cautions and warnings should be emphasized with the appropriate use of attention-getting properties such as flashing, outline boxes, brightness, size, and/or location. Report No. DOT/FAA/RD-81/38, II stresses the importance of preserving the distinguishing characteristics of caution and warning cues. . Where multi-color

HUD symbols are used for alerts, consideration should be given to ensure consistency between the HUD and the head down flight displays.

Single HUD installations can take credit for the copilot monitoring of head down instruments and alerting systems, for failures of systems, modes, and functions not associated with primary flight displays.

Dual HUD installations require special consideration for alerting systems, since it must be assumed that both pilots will be head up simultaneously. If master alerting indications do not provide sufficient attention to each pilot while using the HUD, then each HUD should provide annunciations that direct the pilot's attention to head down alerting displays. The types of information that should trigger the HUD master alerting display are any cautions or warnings not already duplicated on the HUD from head down primary displays.

Appendix A EXAMPLES FOR THE INCLUSION OF Visual System Elements IN AN ALERTING SYSTEM

Examples are included in this AC/ACJ to help the reader through the detailed design of an alerting system. They are based on experience of existing and recommended alerting systems that comply with the rule. The extent to which these examples are applied to a specific certification program will vary, depending on the types of alerts that are presented, and the level of integration associated with an alerting system.

The visual elements of an alerting system include:

- Master Visual
- Visual Information
- Time-Critical Warning Visual Information

A.1 Master Visual

(1) Number & Location
A warning master visual alert and caution master visual alert should be provided at each pilot's station. Master visual alerts for warnings (Master Warning) and for cautions (Master Caution) should be located directly in front of each pilot in their primary field of view.

(2) Onset/Duration/Cancellation

The onset of a master visual alert should occur in a timeframe appropriate for the alerting condition and the desired response.

The onset of a master visual alert should occur simultaneously with the onset of its related master aural alert or unique tone, and its related visual alert information. Any delays between the onset of the master visual alert and its related master aural alert or unique tone, and its visual alert information should not cause flight crew distraction or confusion.

The onset of master visual alerts for the same condition (warnings, cautions) should occur simultaneously at each pilot's station.

The master visual alert should remain on until it is cancelled either manually by the flight crew, or automatically when the alerting situation no longer exists.

Upon cancellation the alerting mechanisms should be reset to annunciate any subsequent fault condition.

(3) Attention-getting visual characteristics

In addition to color, steady state or flashing master visual alerts may be used, as long as the method employed provides positive attention-getting characteristics. If flashing is used, all master visual alerts should be synchronous to avoid any unnecessary distraction.

(4) Brightness

Master visual alerts should be bright enough to attract the attention of the flight crew in all ambient light conditions.

Manual dimming should not be provided unless the minimum setting retains adequate attention-getting qualities when flying under all ambient light conditions.

(5) Display/Indicator Size and Character Dimensions

Any character types, sizes and fonts should be designed so that the master visual alerts are legible and understandable at the pilot's station where they are installed and should provide suitable attention-getting characteristics.

Master visual alerts that subtend at least 1 degree of visual angle have been shown to be acceptable.

(6) Color
Standard color conventions should be followed for the master visual alerts:

- Red for warning
- Amber/yellow for caution

Master visual alerts for conditions other than warnings or cautions (for example, ATC Datalink alerts) must be in a color other than red or amber/yellow.

(7) Test function

To comply with the safety requirements of FAR/JAR 25.1309, provisions may need to be included to test/verify the operability of the master visual alerts.

A.2 Visual Information

(1) Number & Location

The number of displays that provide warning, caution, and advisory alerts should be determined by a combination of ergonomic, operational and reliability criteria, as well as any flight deck physical space constraints.

The visual information should be located so that both pilots are able to readily identify the alert condition.

All warning and caution visual information linked to a master visual should be grouped together on a single dedicated display area. There may be a separate area for each pilot. Advisory alerts may also be presented on the same display area. The intent is to provide an intuitive and consistent location for the display of information.

(2) Format

A consistent philosophy should be provided for the format of visual information to unambiguously indicate the alert condition. The objectives of the corresponding text message format are to direct the flight crew to the correct checklist procedure, and to minimize the risk of flight crew error.

The alerting philosophy should describe the format for visual information. A consistent format should be used.
A format philosophy should include the following three elements:

- The general heading of the alert, (e.g. HYD, FUEL)

- the specific subsystem or location (e.g. L-R, 1-2), and,
- the nature of the condition (e.g. FAIL, HOT, LOW)

For any given message, the available space on a single page should be able to present the entire text on a single defined area to encourage short and concise messages. Additional lines may be used provided the alert message is clear and unambiguous.

If alerts are presented on a limited display area, an overflow indication should be used to inform the flight crew that additional alerts may be called up for review. A memory indication should be used to indicate the number and urgency level of the alerts that have been stored.

A “collector message” is a technique that can be used to resolve problems of insufficient display space, prioritization of multiple alert conditions, alert information overload and display clutter.

Collector messages should be used where the procedure or action is different for the multiple fault condition than the procedure or action for the individual messages being collected. Example: Non-normal procedures for loss of a single hydraulic system on it’s own is different than non-normal procedures for loss of two hydraulic systems. The messages that are “collected” should be inhibited.

An alphanumeric font should be of a sufficient thickness and size to be readable when users are seated at the normal viewing distance from the screen.

NOTE: Minimum character height of 1/200 of viewing distance has been shown to be acceptable (e.g a viewing distance of 36 inches requires a 0.18 inch character height on the screen)(DOD-CM-400-18-05, p 12-1)

NOTE: Arial and Sans serif fonts have been shown to be acceptable for visual alert text. The size of numbers and letters required to achieve acceptable readability may depend on the display technology used. Stroke width between 10 and 15% of character height appears to be best for word recognition on text displays and extensions of descending letters and ascending letters should be about 40% of letter height.

(3) Color

Standard color conventions should be followed for the visual information:

- Red for warning
- Amber/yellow for caution

Red should be used for indicating a non-normal operational or non-normal aircraft system condition that requires immediate flight crew awareness and immediate action or immediate flight crew decision.

Amber/yellow should be used for indicating a non-normal operational or non-normal aircraft system condition that requires immediate flight crew awareness and future action or future flight crew decision.

In addition to red (for warning) and amber/yellow (for caution), a third color may be used to indicate advisory level alerts, to provide a unique and easily distinguishable coding method for all alerting categories.

Advisories may be any color except red or green, and preferably not amber/yellow. If amber/yellow is used for both caution and advisory messages, the alerting system should provide a distinguishable coding method.

NOTE: Use of red, amber, or yellow not related to caution and warning functions must be minimized to prevent diminishing the attention-getting characteristics of true warnings and cautions
Consistent color conventions for alerts within the cockpit should be provided.

(4) Luminance

The visual alert information should be bright enough so that both pilots are able to readily identify the alert condition in all ambient light conditions.

The luminance of the visual alert information display may be adjusted automatically as ambient lighting conditions inside the flight station change. A manual override control may be provided to enable the pilots to adjust display luminance.

A.3 Time Critical Warning Visual Information

(1) Number & Location

Time-critical warning visual information should be provided directly in front of each pilot within their primary field of view.

Note: The Primary Flight Display (PFD) is used as a practical and preferred display to use as the time critical warning display. Integration of time critical information into the PFD may vary depending on the exact nature of the warning. For example, a dedicated location on the PFD may be used both as an attention-getting function and a Visual Information Display by displaying alerts such as “WINDSHEAR”, “SINK RATE”, “PULL UP”, “TERRAIN AHEAD”, “CLIMB, CLIMB” etc. In addition, graphic displays of target pitch attitudes for TCAS RAs and Terrain may also be included.

(2) Format

Time critical warning visual information must be consistent with the corresponding time critical warning aural information.

Time critical warning visual information may be presented as a text message (for example, “WINDSHEAR”). Certain time critical warning visual information, including guidance, may be presented graphically (for example, TCAS Resolution Advisory)

Text messages that are used for time-critical warning visual information should be red.

The time-critical warning visual information should be erased when corrective actions have been taken, or when the alerting situation no longer exists

(3) Size

An acceptable means of a time-critical display is to subtend at least two square degrees of visual angle, to immediately attract the attention of the flight crews and to modify their habit pattern for responding to non-time-critical alerts.

A.4 Failure Flags

The use of failure flags on flight deck instruments is a means of indicating failures of displayed parameters or it’s data source. In the sense that these flags indicate failures of airplane systems they have been displayed using colors that are the same as for crew alerts. Failure flags are typically associated with only single instrument displays and as such don’t necessarily satisfy all of the guidance material for flight crew alerts in general. However, in the integrated environment of the flight deck it is appropriate to display instrument failure flags in a color consistent with the alerting system, as part of the alerting function(see paragraph 8d) Conditions that set failure flags may also generate flight crew alerts and the subsequent flight deck indications should be consistent.

Appendix B EXAMPLES FOR INCLUSION OF Aural System Elements IN AN ALERTING SYSTEM

Examples are included in this AC/ACJ to help the reader through the detailed design of an alerting system. They are based on experience of existing and recommended alerting systems that should comply with the rule. The extent to which these examples are applied to a specific certification program will vary, depending on the types of alerts that are presented, and the level of integration associated with an alerting system.

The aural elements of an alerting system include:

- Unique tones, including master aural alerts
- voice information

Each sound should differ from other sounds in more than one dimension (e.g. frequency, sequence, intensity) so that each one is easily distinguishable from the others.

B.1 Master Aural Alert and Unique Tones

(1) Frequency

Aural signals using frequencies between 200 and 4500 Hz have been found to be acceptable.

Aural signals composed of at least two different frequencies or aural signals composed of only one frequency that contain different characteristics (e.g. spacing) have been found to be acceptable.

To minimize masking, frequencies different from those that dominate background noise should be used

(2) Intensity

The aural alerting must be audible to the flight crew in the worst-case (ambient noise) flight conditions whether or not the flight crew is wearing headsets (taking into account their noise attenuation characteristics). The aural alerting should not be so loud and intrusive as to interfere with the flight crew taking the required action.

The minimum volume achievable by any adjustment (manual or automatic) (if provided) of aural alerts should be adequate to ensure it can be heard by the flight crew if the level of flight deck noise subsequently increases.

Automatic volume control is recommended to maintain an acceptable signal-to-noise ratio

(3) Number of Sounds

The number of different master aural alerts and unique tones should be limited, based on the ability of the flight crew to readily obtain information from each alert and tone. While different studies have resulted in different answers, in general these studies conclude that the number of unique tones should be less than 10.

One unique tone for master warning and one unique tone for master caution should be provided. A master aural tone for advisories is not recommended.

(4) Onset/Duration

It is recommended that an onset and offset of any aural alert or unique tone be ramped to avoid startling the flight crew.

- A duration for onsets and offsets of 20-30 ms in the region above threshold has been shown to be acceptable.

- An onset level of 20-30 dB above the flight deck ambient threshold has been shown to be acceptable.

The onset of the master aural alert or unique tone should occur in a timeframe appropriate for the alerting condition and the desired response. Any delays between the onset of the master aural alert or unique tone and its related visual alert should not cause flight crew distraction or confusion.

If more than one source of the master aural alert or unique tone is provided, the master aural alert or unique tone for the same condition should occur simultaneously and synchronously at each pilot's station. Any timing differences should not be distracting nor should they interfere with identification of the aural alert or unique tone.

Signal duration of the master aural alert and unique tones should vary, depending on the alert urgency level and the type of response desired.

Unique tones associated with time-critical warnings should be repeated and non-cancellable until the alerting condition no longer exists (e.g. stall warning), unless it interferes with the flight crew's ability to respond to the alerting condition.

Unique tones associated with warnings should be repeated and non-cancellable if the flight crew needs continuous awareness that the condition still exists, to support the flight crew in taking corrective action (ref. 1303.c.(1), Flight and Navigation Instruments, and 25.729.e, Retracting Mechanism)

Unique tones associated with warnings should be repeated and cancellable if the flight crew does not need continuous aural indication that the condition still exists (e.g. Fire Bell, Abnormal Autopilot Disconnect).

Unique tones associated with warnings should be non-repeatable if the flight crew does not need continuous aural indication that the condition still exists.

Master warnings should be repeated and non-cancellable if the flight crew needs continuous awareness that the condition still exists, to support the flight crew in taking corrective action (e.g. FAR/JAR 25.729(e) 2).

Master aural warnings should be repeatable until the flight crew acknowledges the warning condition or when the warning condition no longer exists.

For master aural cautions and unique tones associated with a caution, the sound should be limited in duration or can be continuous until the flight crew manually cancels it, or when the caution condition no longer exists.

Unique tones that are neither associated with a warning nor a caution (e.g. certain advisories, altitude alert, SELCAL), should be limited in duration.

(5) Cancellation

For caution level alerts, the master aural and unique tone should continue through one presentation and cancel automatically.

If there is any tone associated with an advisory, it should be presented once and then cancelled automatically.

A means must be provided to reactivate the aurals when canceled.

When silenced, the aurals may be capable of re-arming automatically. However, if there is a clear and unmistakable annunciation in the pilot's forward field of view that the aurals are silenced, manual re-arming is acceptable.

B.2 Voice Information

NOTE: The purpose for using voice information is to indicate conditions that demand immediate flight crew awareness of a specific condition without further reference to other indications in the flight deck.

Effects of using voice information include:
- To limit the number of unique tones
- To transfer workload from the visual to the auditory channel
- To enhance the identification of an abnormal condition, and effectively augment the visual indication without replacing its usefulness
- To provide information to the flight crew where a voice message is preferable to other methods
- Where awareness of the alert must be assured no matter where the pilot's eyes are pointed

(1) Voice Characteristics

The voice characteristics should be distinctive and intelligible.

Voice characteristics should include attention-getting qualities appropriate for the level of the alert.

(2) Voice Inflection

Voice inflection has been used in the past to indicate a sense of urgency. However, an alarming tone indicating tension or panic is not recommended, since it may be inappropriately interpreted by flight crews of differing cultures. Depending on the alerting condition, advising and commanding inflections may be used to facilitate corrective action, but the content of the message itself should be sufficient.

(3) Intensity

The aural alerting must be audible to the flight crew in the worst-case (ambient noise) flight conditions whether or not the flight crew is wearing headsets (taking into account their noise attenuation characteristics). The aural alerting should not be so loud and intrusive as to interfere with the flight crew taking the required action.
The minimum volume achievable by any adjustment (manual or automatic) (if provided) of aural alerts should be adequate to ensure it can be heard by the flight crew if the level of flight deck noise subsequently increases.

Automatic volume control is recommended to maintain an acceptable signal-to-noise ratio

(4) Onset/Duration

The onset of the voice information should occur in a timeframe appropriate for the alerting condition and the desired response.

The onset of the voice information should occur simultaneously with the onset of its related visual alert information. Any delays between the onset of the voice information and its related visual alert should not cause flight crew distraction or confusion.

If more than one source of the voice information is provided for the same condition, they should occur simultaneously and synchronously at each pilot's station so that intelligibility is not affected.

Voice information associated with time-critical warnings should be repeated and non-cancellable until the alerting condition no longer exists (e.g. terrain warning).
However, voice information associated with time-critical warnings should *not* be repeated if they interfere with the flight crew's ability to respond to the alerting condition (e.g. windshear warning, TCAS resolution advisory).

Voice information associated with warnings should be repeated and non-cancellable if the flight crew needs continuous awareness that the condition still exists, to support the flight crew in taking corrective action.
However, voice information associated with warnings should be repeated and cancellable if the flight crew does not need continuous aural indication that the condition still exists (e.g. Cabin Altitude Warning, Autopilot Disconnect).

Upon cancellation the alerting mechanisms should be reset to annunciate any subsequent fault condition.

For voice alerts associated with a caution, the corresponding voice information should be limited in duration (e.g. TCAS Traffic Advisory, Windshear Caution) or can be continuous until the flight crew manually cancels it or the caution condition no longer exists.

(5) Voice information Content

The content of the voice information should consider the flight crew's ability to understand the English language.

It may be acceptable to consider the use of languages other than aviation English (either replaced entirely or alternating with a native language).

For time-critical warnings, the content and vocabulary of voice information should elicit the immediate (instinctive) corrective action. In order to elicit immediate (instinctive) corrective action, it should provide identification of the condition. In some cases, it may also be necessary to include guidance or instruction information.

For warnings and cautions the content of voice information should provide an indication of the nature of the condition.

The content should be consistent with any related visual information display.

Voice information that use more than one word should be structured to avoid incorrect or misleading information if one or more words are missed (e.g. the word "don't" at the beginning of a voice message should be avoided).

Voice information should be designed to minimize confusion with each other.

Date: June 23, 2006

Re: Transport Airplane and Engine Issues Group (TAEIG)
Avionics Systems Harmonization Working Group
Task 4 – Warning, Caution and Advisory Lights

Attn: Mr. Craig Bolt, Assistant Chair, TAEIG

Dear Mr. Bolt,

In accordance with the reference task, the Avionics Systems Harmonization Working Group (ASGWG) is pleased to submit the attached technical report which provides the group's recommendations for a harmonized revision to AC/AMC 25-11 (herein referred to as "the report"). This report is provided for approval by the TAEIG.

In addition to the report, the group would like to bring to your attention the following relevant points:

1) Part of the process included coordination with AIA PITT, to provide technical expertise and input to this draft report. Most of the AIA PITT input is included in this report. However, there are a few items received from AIA PITT which were not incorporated in this report. These are identified as follows:

- Section 6.5, Safety Design Guidelines: "*Loss of one or more required engine indications on more than one engine*" – current draft states this as "remote" however PITT requested that it be listed as "extremely remote"
- Section 6.5, Safety Design Guidelines: "*Display of misleading required engine indications on more than one engine*" – current draft states this as "extremely remote" however PITT requested that it be listed as "extremely improbable"

  ASHWG Response: With the improvement of display systems, introduction of fully autonomous engine controls, and other mitigating factors, both safety objectives have been accepted in recent certifications. The report's section on safety design lists these as "Examples of generally accepted safety objectives for engine related failure conditions," and in the case of engine indications the assumption is made (and clearly stated) that a fully autonomous engine control is provided.

  The ASHWG position is to provide only guidance (objectives) for certain failure conditions, and that they need to be substantiated (or changed) through the development of an airplane Functional Hazard Assessment. The basis for a higher minimum objective applied to display system indications (e.g. specific scenarios) need to be provided.

  A suggestion for resolution is to omit these specific safety objectives and point to AMC 901 (c) and a previously generated ARAC report for AC 901 (c) – note that the AC is an ARAC recommended draft since 1998 but it is not yet released. This wording was considered but not incorporated in our draft document.

- Appendix B, Powerplant Indications - AIA PITT requested the addition of the following: "*No single failure may cause misleading indications on more than one engine. [ref., §25.903(b)].*"

  ASHWG Response: ASHWG rejected this input since there are common mode failures in any display system (e.g. design errors) that can not meet this requirement – for any display indication not just engine indications. In addition no safety objective or failure classification is provided.

- Appendix B, Powerplant Indications - AIA PITT requested the addition of the following: "*No single failure should cause the loss of all thrust setting parameters on more than one engine [ref. §25.901(b)(2), §25.901(c), §25.1301, §25.1305 §25.1309].*"

ASHWG Response: ASHWG rejected this input since there are common mode failures in any display system (e.g. design errors) that can not meet this requirement – for any display indication not just engine indications. In addition no safety objective or failure classification is provided.

- Appendix B, Powerplant Indications - AIA PITT requested the addition of the following: *"For single failures leading to the partial loss of indications on an engine, sufficient indications should remain to allow continued safe operation of the engine [ref. §25.901(b)(2), §25.901(c), §25.903(d)(2)]"*

  ASHWG Response: ASHWG generally accepted this but included the idea of non-recoverable loss of indications. There may be procedures that the flight crew can perform to recover the loss of a display indication (e.g. display reversion). Proposed text that was incorporated in this report: *For single failures leading to the non-recoverable loss of any indications on an engine, sufficient indications should remain to allow continued safe operation of the engine [ref. §25.901(b)(2), §25.901(c), §25.903(d)(2)]*

- Appendix B, Powerplant Indications - AIA PITT requested the addition of the following *"Indications required for continued safe operation of the engines, including engine restart, should be displayed after the loss of normal electrical power. "*

  ASHWG Response: This was considered unnecessary since the failure condition in section 6.5 *"Loss of one or more required engine indications on a single engine"* would need to be met through a system safety assessment that considers many causes, including the loss of electrical power. Therefore this statement is redundant.

- One of the CAST objectives assigned to the ASHWG is related to powerplant indications was coordinate with AIA PITT and discussed below (with the complete list of CAST objectives).

2) After the formal task for AC/AMC 25-11 was released, the ASHWG was further tasked with incorporating the recommendations made by the Commercial Aviation Safety Team (CAST), as a result of the report named "Enhancement 34: Implement certain display/alerting features (see next slide) on all new airplane cert and future derivative model planes." This is driving the current delivery date of this report.

Since this is an AC/AMC, the group can not provide wording which requires the inclusion of these enhancements. Our wording reflects the guidance that the ASHWG feels is appropriate for an AC/AMC.

Each CAST enhancement item, along with the relevant text from the report (or other response from the ASHWG) is identified below:

- Graphical depiction of vertical situation – real time graphical depiction of their vertical situation

  ASHWG Response: Group position is to not explicitly state (require) VSD, but to include considerations for implementation within the current context of this AC. This report is not prescribing functionality unless required by regulation.

  Current text included in section 8 of the draft AC/AMC: *"Information such as navigation information, weather, and vertical situation display is often displayed on Multi-Function Displays (MFD) which may be displayed on one or more physical electronic displays or on areas of a larger display. When this information is not required to be displayed continuously, it can be displayed part-time."*

  Current text included in section 7 of the report: *Depictions include schematics, synoptics, and other graphic depictions such as attitude indications, moving maps, and vertical situation displays.*

  To avoid visual clutter, graphic elements should be included only if they add useful information content, reduce flight crew access or interpretation time, or decrease the probability of interpretation error.

To the extent it is practical and necessary, the graphic orientation and the flight crews' frame of reference should be correlated. For example, left indications should be on the left side of the graphic and higher altitudes should be shown above lower altitudes..

Graphics that include three-dimensional effects should ensure the symbol elements being used to achieve these effects would not be interpreted as information in and of themselves.

In addition TSO-C165, "Electronic Map Display Equipment for Graphical Depiction of Aircraft Position," specifically addresses vertical situation displays.

- Graphic speed trend information

ASHWG Response: Current text included in Appendix A of the report: *Airspeed scale graduations found to be acceptable have been in 5-knot increments with graduations labeled at 20-knot intervals.* ***In addition, a means to rapidly identify a change in airspeed (e.g. speed trend vector or acceleration cue) should be provided****; if trend or acceleration cues are used, or a numeric present value readout is incorporated, scale markings at 10-knot intervals have been found acceptable.*

Vertically oriented moving scale airspeed indication is acceptable with higher numbers at the top or bottom if no airspeed trend or acceleration cues are associated with the speed scale. Such cues should be oriented so that increasing energy or speed results in upward motion of the cue.

- Pitch Limit Indication

ASHWG Response: Current text included in Appendix A of the report: *There should be a means to determine the margin to stall and display it when necessary. For example, a pitch limit indication has been found to be acceptable*

- Bank angle limits to buffet

ASHWG Response: Current text included in Appendix A of the report: *There should be a means to identify an excessive bank angle condition prior to stall buffet.*

- Barber poles/amber bands (minimum and maximum speeds)

ASHWG Response: Current text included in Appendix A of the report: *Airspeed scale markings that remain relatively fixed (such as stall warning, VMO/MMO), or that are configuration dependent (such as flap limits), should be displayed to provide the flight crew a quick-glance sense of speed. The markings should be predominant enough to confer the quick-glance sense information, but not so predominant as to be distracting when operating normally near those speeds (e.g., stabilized approach operating between stall warning and flap limit speeds).*

- Detection and annunciation of conflicting attitude, airspeed and altitude information

ASHWG Response: Current text included in Section 6 of the report: *There should be a means to detect and provide immediate awareness of conflicting attitude, altitude, and airspeed information between the captain and the first officer.*

- Detection and removal of invalid attitude, airspeed and altitude info, and
- Detection and removal of misleading attitude, airspeed and altitude info (i.e. from an external fault)

ASHWG Response: In this particular case "misleading" is interpreted as being "incorrect." There are cases where there may not be the capability to determine which source is incorrect. Both CAST items are addressed as follows:

Current text included in Section 6 of the report: *There should be a means to detect lost or erroneous primary flight information, either as a result of a display system failure or a failure of the associated sensor. This means should be sufficient to ensure that the lost or erroneous information is not useable by the flight crew (e.g. removal of the information, "X" through the failed display).*

- Information to perform effective manual recovery from unusual attitudes using chevrons, sky pointers, and/or permanent ground-sky horizon on all attitude indications

  <u>ASHWG Response:</u> Current text included in Appendix A of the report: *An accurate, easy, quick-glance interpretation of attitude should be possible for all unusual attitude situations. Information to perform effective manual recovery from unusual attitudes using chevrons, sky pointers, and/or permanent ground-sky horizon on all attitude indications is recommended.*

- Salient annunciation of autoflight mode changes and engagement status

  <u>ASHWG Response</u>: This is already addressed in AC 25-1329B, Chapter 4, paragraph 44:
    a. Annunciation of Engagement of the FGS
    b. Description of FGS Modes
    c. FGS Mode Annunciations
    d. Mode Changes
    e. Failure to Engage or Arm
    f. FGS mode Display and Indications

- Effective sideslip information and alerting of excessive sideslip (ex split trapezoid)

  <u>ASHWG Response:</u> Current text included in Appendix A of the report: *Sideslip should be clearly indicated to the flight crew (e.g. split trapezoid on attitude indicator), and an indication of excessive sideslip should be provided.*

- Clear annunciation of engine limit exceedances and significant thrust loss

  <u>ASHWG Response</u>: The following text has been added to Appendix B of the report:.

  "Safety-related engine limit exceedances should be indicated in a clear and unambiguous manner. Flight crew alerting is addressed in 14CFR/CS §25.1322."

  "If an indication of significant thrust loss is provided it should be presented in a clear and unambiguous manner."

  Additional input from AIA PITT re: Indication of Engine Exceedance:
  AIA PITT feels that the display aspect of engine exceedance is covered by 25.1322 / AC25.1322, 25.1305, 25.1521, 25.1583.

  Additional input from AIA PITT re: Significant Thrust Loss:
  There is an entire section specifically devoted to the subject of Undetected Thrust Loss in the ARAC recommended Draft AC25.901(c) (circa 1998).

  EASA released the material in an NPA in 2004
  (http://www.easa.eu.int/doc/Rulemaking/NPA/NPA_13_2004.pdf)

  The FAA has worked on the AC but not yet released it. There is an FAA Policy which says we can use this proposed draft AC as the basis for an ESF with the current §25.901(c), although no one has yet done so.

In addition to the proposed text in the report, the ASHWG recommends that the FAA release AC25.901(c).

3) The current draft of the report includes pointers to the ARAC reports for 25.1302 and 25.1322. EASA has already released an NPA for 25.1302 and is planning to release a NPA for 25.1322. This group strongly requests that the final rules and associated ACs be prioritized such that they are published simultaneously with the publication of AC 25-11. Our original task was drafted assuming that 25.1302 and 25.1322 would be released prior to the release of AC/AMC 25-11. There is a potential for lack of harmonization between FAA and EASA, and inconsistent application of new vs. old regulations should the release of 25.1302 and 25.1322 be delayed.

4) Industry is concerned that without further harmonization between EASA and the FAA there will be an increase in the cost to develop and certify new capabilities such as HUD, EVS, and SVS. Industry burden of these costs and impacts to schedule are mitigated by the coordinated guidance provided by the multi-disciplinary and regulatory harmonization process.

A significant part of the industry rationale for creating a harmonized AC/AMC 25-11 was a result of the latest capabilities and technologies being introduced, without any airworthiness guidance (e.g. HUD, EVS, and SVS). This group was originally tasked with, and intended on drafting harmonized material for HUD, EVS, and SVS, but was forced to drop activity on these subjects based on the deadline to meet CAST objectives.

EASA is planning to continue drafting guidance for HUD, EVS, and SVS, and this group strongly requests that the TAEIG provide additional tasking to develop a harmonized update to AC/AMC 25-11 to include HUD, EVS, and SVS.

5) The ASHWG expects to disposition the public comments, in a typical ARAC forum with the content experts from the FAA, EASA, AIA PITT, and industry. This group believes that each of the member companies will be providing a significant amount of comments, based on the significant amount of original comments received while writing the draft report.

Please do not hesitate to contact me if you have any questions.

Sincerely,

Clark Badie
Co-Chair, ASHWG
Tel: 602-436-5089
e-mail: clark.badie@honeywell.com

U.S. Department
of Transportation
**Federal Aviation
Administration**

800 Independence Ave., S.W
Washington, D.C. 20591

NOV - 1 2006

Mr. Craig R. Bolt
Assistant Chair, Aviation Rulemaking
Advisory Committee
Pratt & Whitney
400 Main Street, Mail Stop 162-14
East Hartford, CT 06108

Dear Mr. Bolt:

This is in reply to your August 4, 2006, letter transmitting recommendations for revisions to guidance material for electronic flight deck displays. We appreciate and value the coordinated effort between the Avionics Systems Harmonization Working Group (ASHWG), the Human Factors Harmonization Working Group, and the Powerplant Indication Task Team on this important safety initiative.

In your letter, you emphasize the importance of the Federal Aviation Administration (FAA) and the European Aviation Safety Agency (EASA) harmonization of this recommendation. Be assured that we are working closely with EASA and other aviation authorities to maximize harmonization of guidance material on this subject.

I wish to thank the Aviation Rulemaking Advisory Committee (ARAC), especially the members associated with Transport Airplane and Engine Issues, and its working groups that provided resources to develop the report. The report will be placed on the ARAC website at: http://www.faa.gov/regulations_policies/rulemaking/committees/arac/.

We understand the ASHWG will continue to develop appendix material to support completion of this task. We shall keep the committee apprised of the agency's efforts on this recommendation through the FAA report at future committee meetings.

Sincerely,

Nick Sabatini

Nicholas A. Sabatini
Associate Administrator for Aviation Safety

Draft AC/AMC 25-11 – Electronic Flight Deck Displays

Draft	Date	Description of Changes
A	October 2004	First draft. Main sections drafted include: 7.3 Optical; 8.1 Criticality; 9.2.3 Symbology; 10 Information Management; 10.2 Windowing, 10.3 Basic T Format; 10.5.1. Menuing; 10.5.2 Linking; 10.7 Failure Modes; 11 Interactivity; 12 Test and evaluation; 14 Continued Airworthiness; TBD EVS; TBD Situational Awareness Display
B	January 2004	Includes all material reviewed at the January 2004 meeting. Updates for sections: 1 Purpose; 2 Scope; 3 Background; 9.2.2 Labeling; 9.2.3 Symbology; 9.2.5 Color; 9.3.1 Dynamic Coding; 9.3.2 Data Display Dynamics; 9.4.1 Data Mingling; 9.4.4 Overall Formats Consistency; 12 Test and Evaluation; 14 Continued Airworthiness; Section 1 -
C	April 2004	Includes material reviewed at the April 2004 London meeting
D	July 2004	Includes all material prepared prior and during the July 2004 Toulouse meeting, does not include comments discussed during the plenary session. Updates for sections : 2 scope, 5 Definition, 7 Display characteristics, 8 safety aspects, 9 Display functions,10 Information management, 12 Test and Evaluation, App C HUD, App E Synthetic Vision
E	October 2004	Includes all material drafted during the October 2004 Dallas meeting. Updates for sections: 2 – Scope, 5 – Definition, 6 – Related Regulations, 7 – Display Characteristics, 8 – Safety Aspects, 9 – Display Functions, 10 – Information Management, 11 – Interactivity, 12 – Certification Considerations, 13 (Deleted), 14 Renumbered to 13, Appendix Table of Hazard Classifications, subsequent draft appendices were moved to insert appendix A
F	Jan 2005	Filename “Draft AC-AMC 25-11 Jan 2005 post_Savannah_meeting_v1.doc” Includes updates from Savannah Meeting (Jan 2005)- specifically updates to Sections: 4 Glossary 5 Definitions 9 Display Functions 10 Information Management 11 Interactivity
G	Apr 2005	Filename Includes updates from Bordeaux meeting (April 2005) with specific comments from the AVHWG team members. All sections affected.
H	Jun 2005	Includes updates from the Paris meeting (June 2005), incorporating the disposition of all internal comments. Sections were re-ordered.
I	Oct 2005	Includes updates to section 7 from Stephane (7.3.4.1 & 7.3.4.2) from the PITT input, includes Ian’s input to Integrated Standby Appendix (was Appendix H and is now Appendix C), updates to section 4 made on Friday and Section 10 made on Friday. Includes changes made to Appendix A and Appendix B, as well as changes to sections 6 and 8 from the PITT input
J	Mar 2006	Includes changes made as a result of company comments. Ch 1, 2, 3, 5, 6, 8 and 11.
K	Apr 2006	Includes changes made from the AVHWG meeting, April 2006
L	June 2006	Includes changes made at late May pre-meeting and June 2006 team meeting – prepared for release

1 Purpose

This advisory circular/acceptable means of compliance (AC/AMC) provides guidance for the design, integration, installation, and approval of electronic flight deck displays and display systems installed in transport category airplanes. Like all AC/AMC material, this AC/AMC is not mandatory and does not constitute a regulation. It is issued to minimize the need for additional interpretation and to provide guidance for a means of compliance with Title 14 of the Code of Federal Regulations (14 CFR)/CS25 Certification Specifications for Large Airplanes applicable to the installation of electronic displays in Part 25 airplanes.

While these guidelines are not mandatory, they are derived from extensive regulatory and industry experience in determining compliance with the relevant regulations. A means of compliance shall be established using this AC or an acceptable alternative method proposed by the applicant.

2 Scope

This AC applies to the design, integration, installation, and certification of electronic flight deck displays, components, and systems for Transport Category airplanes. As a minimum this includes:

- general airworthiness considerations
- display system and component characteristics
- safety and criticality aspects
- functional characteristics
- display information characteristics
- guidance to manage display information
- flight crew interface and interactivity,
- airworthiness approval (means of compliance) considerations.

In scope	**Out of scope**
Electronic Pilot displays (front panel) – including single function and multi-function displays	In flight entertainment (IFE) displays
	Flight attendant displays
	Maintenance terminals, even if they are in the flight deck, but not intended for use by the pilots
Cabin surveillance if being used on the front panel or side panel displays	Displays in the crew rest area
Display functions intended for use by the pilot, or display aspects of other functions intended for use by the pilot	Display functions not intended for use by the pilot
Display functions not intended for use by the pilot if they may interfere with the pilot's flying duties	Handheld or laptop items (not installed equipment)
Display aspects of class III Electronic Flight Bag (EFB) (installed equipment)	Class I and Class II EFB
	Electromechanical instruments
Visual electronic displays	Auditory "displays" (e.g. aural alerts), tactile "displays" (e.g. stick shaker)
Controls associated with items in this column – includes hard controls (physical buttons and knobs) and soft controls (virtual buttons and knobs, generally controlled through a cursor device)	Flight controls, throttles, other (hard) controls not directly associated with the electronic displays
Electronic standby displays	

Table 2-1: In-scope and out-of-scope guidelines for the applicability of AC/AMC 25-11

Editorial note – change so that these are not tables, replace with bullet lists

This AC is intended to supersede the original AC 25-11, dated 16 July 1987, and AMJ 25-11.

In addition to this AC, a new AC/AMC 25-1302 has been proposed to provide acceptable means of compliance for many rules associated with certification of the design of flight crew interfaces such as displays, indications, and controls. A new AC/AMC 25-1322 has also been proposed to provide means of compliance for flight deck alerting systems.

The combination of the guidance listed in this document along with the proposed AC/AMJ 25-1302 and AC/AMC 25-1322 is intended to embody a variety of design characteristics and human-centered design techniques that have wide acceptance, are relevant to the regulatory requirements, and can be reasonably applied to transport airplane certification programs.

The links below include information about the recommendations for the proposed AC/AMC 25.1302 and AC/AMC 25.1322, respectively.

http://www.faa.gov/regulations_policies/rulemaking/committees/arac/media/tae/TAE_HFH_T1.pdf
http://www.faa.gov/regulations_policies/rulemaking/committees/arac/media/tae/TAE_ASH_T4.pdf

For the purposes of this AC/AMC a "Display System" includes not only the display hardware and software components. Hardware and software components of other systems that affect displays, display functions, or display controls have to take into account the display aspects of this AC/AMC. For example, this AC/AMC would be applicable to a barometric set display, even though the barometric set function may be part of another system.

For the purposes of this AC/AMC, "foreseeable conditions" is the full environment that the display or the display system is assumed to operate within, given its intended function. This includes operating in normal, non-normal, and emergency conditions.

Other advisory material is used to establish guidance for specific functionality and characteristics provided by electronic displays. For example, AC 25-23 describes a means for airworthiness approval of Terrain Awareness and Warning System (TAWS), and includes guidance on the display of TAWS. This AC/AMC is not intended to replace or conflict with these existing ACs/AMCs but rather provides a top-level view of flight deck displays. Conflicts between this AC/AMC and other advisory material will be resolved on a case-by-case basis in agreement with the authorities.

The acronyms and abbreviations used throughout this document are defined in section 12. Definitions of technical terms used in this AC can be found in section 13. A list of applicable regulations, and related guidance and industry material is included in section 14.

3 Background

The FAA and EASA have established a number of regulatory requirements intended to improve aviation safety by requiring that the flight deck design have certain capabilities and characteristics. Certification of flight deck displays and display systems has typically been addressed by invoking many rules that are specific to certain systems, or to rules with general applicability such as 25.1301(a), 25.771(a), and 25.1523.

Electronic displays can present unique opportunities and challenges to the design and certification process. In many cases, showing compliance with regulatory requirements related to the latest flight deck display system capabilities has been subject to a great deal of interpretation.

The initial release of Advisory Circular 25-11 (16 July 1987) established guidance for the approval of cathode ray tube (CRT) based electronic display systems used for guidance, control, or decision-making by the flight crews of transport category airplanes. At the time the first electronic displays were developed, they were direct replacements for the conventional electromechanical components. This guidance has been updated in accordance with the latest-generation display technologies as well as other improvements in flight deck designs.

4 General

This section provides guidance that applies to the overall electronic display. The remainder of this section, together with sections 5 through 9, provides compliance objectives and design guidance. Section 10 provides general guidance on how to show compliance (such as, analysis or evaluation). The material in Sections 4 through 9, together with the process for identifying and applying appropriate means of compliance (Section 10) constitutes an overall method of compliance for certifying an electronic display.

The applicant should establish, document and follow a design philosophy for the display system that supports the intended function, including a high level description of:

1. General philosophy of information presentation – e.g., is a “quiet, dark” flight deck philosophy used or is some other approach used?

2. Color philosophy on the electronic displays – the meaning and intended interpretation of different colors – e.g., magenta represents a constraint.

3. Information management philosophy– e.g., when should the pilot take an action to retrieve information or is it brought up automatically? When and where? What is the intended interpretation of location of information?

4. Interactivity philosophy- e.g., when and why confirmation of actions is requested. When is feedback provided?

Human performance considerations include flight crew workload, training time to become sufficiently familiar with interfacing with the display, the potential for flight crew error, system ease of use, and pilot concentration required to use the display. For example, high workload or excessive training time may indicate a display design that is difficult to use, requires excessive concentration, or may be prone to flight crew errors.

The certification plan for an electronic display system should include a description of the intended function. To demonstrate compliance with §25.1301(a), an applicant must show that the design is appropriate for its intended function. The applicant’s description of intended function must be sufficiently specific and detailed for the Authority to be able to evaluate that the system is appropriate to its intended function. General and/or ambiguous intended function descriptions are not acceptable (e.g., a function described only as “situation awareness”). More detailed descriptions may be warranted for designs that are new, novel, highly integrated, or complex. A system description is one way to document the intended function(s).

Display systems and display components that are not intended for use by the flight crew (such as maintenance displays) should not interfere with the flying duties of the flight crew.

5 Display Hardware Characteristics

This section provides general guidance and a means of compliance for electronic display hardware with respect to its basic optical and installation characteristics. A more detailed set of guidelines for electronic display hardware can be found in SAE ARP 4256A and SAE AS8034A for head down displays and SAE AS 8055 for head up displays

5.1 Hardware Optical characteristics

The visual display characteristics of a flight deck display are directly linked to their optical characteristics. A set of nine basic parameters, which are independent of the technology, provides a means of compliance to flight deck performance requirements. In addition, the visual display characteristics should provide performance that is in accordance with section 7 of this AC/AMC.

Display defects (e.g. element defects, stroke tails) should not impair readability of the display or create erroneous interpretation.

(1) Image Size
The display image size should be large enough to display information in a form that is useable (e.g. readable, identifiable) to the flight crew and in accordance with its intended function(s).

(2) Resolution and line width
The resolution and minimum line width should be sufficient to support all the operational images without misinterpretation of the displayed information.

(3) Luminance
Information should be readable over a wide range of ambient illumination under all foreseeable operating conditions including but not limited to:

- Direct sunlight on the display
- Sunlight through a front window illuminating white shirts (reflections)
- Sun above the forward horizon and above a cloud deck in the flight crew member's eyes
- Night and/or dark environment.

For low ambient conditions, the display should be dimmable to levels allowing for the flight crew's dark ambient adaptation, such that outside vision is maintained while maintaining an acceptable presentation.

Display luminance variation within the entire flight deck should be minimized so that displayed symbols, lines, or characters of equal luminance remain uniform under any luminance setting and under all foreseeable operating conditions.

(4) Contrast Ratio
The Contrast Ratio of the display should be sufficient to ensure that display information is discernable under the whole ambient illumination range under all foreseeable operating conditions.

The contrast between all symbols, characters, lines, and their associated backgrounds should be sufficient to preclude confusion or ambiguity as to information content of any necessary information.

(5) Chromaticity
The display chromaticity range should be sufficient to allow graphic symbols to be discriminated from their background (external scene, image background) and other symbols in all ambient conditions. Raster or Video fields (e.g. non-vector graphics) such as weather radar should allow the image to be discriminated from overlaid symbols, and should allow the desired graphic symbols to be displayed.

The display should provide chromaticity stability over the foreseeable range of operating temperatures, viewing envelope, and dimming range such that the symbology is not misleading.

(6) Gray Scale

The number of shades of gray and the difference between shades of gray that the display can provide should depend on the image content and its use, and should accommodate for all viewing conditions.

The display should provide sufficient gray scale stability over the foreseeable range of operating temperatures, viewing envelope, and dimming range.

(7) Flight Deck Viewing Envelope

The size of the viewing envelope should provide the flight crew with visibility of the flight deck displays over their normal range of head motion, and to support cross-flight deck viewing if necessary (for example, when it is required that the captain be able to view and use the first officer's primary flight information).

(8) Display Response

The display response should be sufficient to provide discernability and readability of the displayed information without presenting misleading information. The response time should be sufficient to ensure dynamic stability of colors, line widths, gray scale and relative positioning of symbols by minimizing artifacts such as smearing of moving images and loss of luminance.

(9) Display Refresh Rate

The display refresh rate (e.g. update rate of an LCD) should be sufficient to prevent smearing and flicker effects that result in misleading information.

5.2 Display Hardware Installation

Flight deck display equipment and installation designs should be compatible with the overall flight deck design characteristics (such as flight deck size and shape, flight crew member position, position of windows, external luminance, etc.) as well as the airplane environment (such as temperature, altitude, electromagnetic interference, vibration).

RTCA document DO-160E and EUROCAE document ED-14E (or later applicable versions) provide information to be used for an acceptable means of qualifying display equipment for use in the airplane environment.

The display unit must be located in the flight deck such that airspeed, altitude, attitude, and heading information are not visually obstructed (25.1321(a)).

The installation of the display equipment should not adversely impair its readability and the external scene visibility of the flight crew under all foreseeable flight deck lighting conditions (25.1321(a), 25.773 (a)(1))

The installation of the display equipment must not cause glare or reflection that could interfere with the normal duties of the flight crew. (25.773 (a)(2))

If the display system design is dependent on cross-flight deck viewing for its operation, the installation should take into account the viewing angle limitations of the display units, the size of the displayed information, and the distance of the display from each flight crew member.

When a display is used to align or overlay symbols with real-world external data (i.e. conformal), the display should be installed such that positioning accuracy of these symbols is maintained during all phases of flight (e.g. HUD symbols). SAE ARP 5288 describes in additional detail the symbol positioning accuracy for conformal symbology on a HUD.

The display system components should not cause physical harm to the flight crew under foreseeable operating conditions.

The display system should not be adversely susceptible to electromagnetic interference from other airplane systems (25.1431).

When installed the display should not visually obstruct other controls and instruments that prevent those controls and instruments from performing their intended function (25.1301).

The display components should be installed in such a way that they retain mechanical integrity (secured in position) for all foreseeable flight conditions.

Liquid spill on or breakage of a display system component should not result in a hazard.

5.3 Power Bus Transient

RTCA document DO-160E and EUROCAE document ED-14E (or later applicable versions) provides information to be used for an acceptable means of qualifying display equipment such that they perform their intended function when subjected to anomalous input power. SAE ARP 4256A provides some additional information for power transient recovery (specifically for the display unit).

Flight deck displays and display systems should be insensitive to power transients caused by normal load switching operation of the airplane, in accordance with their intended function.

Non-normal bus transients other than those caused by engine failure (e.g. generator failure) should not initiate a power up initialization or cold start process.

The display response to a short term power interrupt (<200ms) should be such that the intended function of the display is not adversely affected.

Following in-flight long term power interrupts (>200ms), the display system should quickly return to operation in accordance with its intended function, and should continue to permit the safe control of the airplane in attitude, altitude, airspeed, and direction.

The large electrical loads required to restart some engine types should not affect more than one pilot's display.

6 Safety Aspects

CFR 14/CS 25.1309 (Equipment, Systems, and Installation) defines the basic safety requirements for airworthiness approval of airplane systems and AC/AMC 25.1309 provides an acceptable means of demonstrating compliance with this rule. This section provides additional guidance and interpretative material for the application of CFR 14/CS 25.1309 and also CFR 14/CS 25.1333(b) to the approval of Display Systems.

ARP4761, "Guidelines and Methods for conducting the safety assessment process on civil airborne systems and equipment" provides a recommended practice that may be used to perform a system safety assessment.

The Failure Condition should identify the impacted functionality, the effect on the airplane and/or its occupants, specify any considerations related to phase of flight and should identify any flight deck indication, flight crew action, or other mitigation means that are relevant.

6.1 Identification of Failure Conditions

One of the initial steps in establishing compliance with CFR 14/CS 25.1309 is to identify the Failure Conditions that are associated with a display or the Display System. This section provides material that may be useful in supporting this initial activity.

The type of the Display System Failure Conditions will depend, to a large extent, upon the architecture, design philosophy and implementation of the system. Types of Failure Conditions should include:

- Loss of function (system or display)
- Failures of software controls and mechanical display controls – loss of function or malfunction such that they perform in an inappropriate manner, including erroneous display control.
- Malfunction (system or display) that could lead to:
    - Partial loss of data
    - Erroneous display of data that could be:
        - Detected by the system (e.g. flagged, comparator alert), or easily detectable by the crew
        - Difficult to detect by the crew or not detectable and assumed to be correct (e.g. "Misleading display of …")

When a flight deck design includes primary and standby displays, consideration should be given to failure conditions involving failures of standby displays in combination with failures of primary displays. The crew may use standby instruments in 2 complementary roles:

- Redundant display to cope with failure of main instruments
- Independent third source of information to resolve inconsistencies between primary instruments

When the display of erroneous information is caused by failure of other systems, which interface with the display system, the effects of these failures may not be limited to the display system. Associated Failure Conditions may be dealt with at the aircraft level and/or within the other systems Safety Analyses as appropriate in order to assess the cumulative effect.

6.2 Effects of Failure Conditions

The effects of failures of a Display System are highly dependent on the flight crew proficiency, flight deck procedures, phase of flight, the type of operations being conducted, instrumental or visual meteorological conditions, and other system protections.

The Failure Condition definition is complete when the effects resulting from "failure" are identified. A complete definition of the Failure Condition and its effect will then support the subsequent Failure Condition classification.

Based on experience of previous airplane certification programs, section 6.5 sets safety objectives for some Failure Conditions. These safety objectives do not preclude the assessment of the actual effects of these failures, which may be more or less severe depending on the design. Therefore the classifications for these Failure Conditions will also need to be agreed with the certification authority during the 14CFR/CS-25.1309 safety assessment process.

When assessing the effects that result from a display failure, the following effects should be considered, accounting for phases of flight when relevant:

- Effects on the flight crew's ability to control the airplane in terms of attitude, speed, accelerations, flight path, potentially resulting in:
    - controlled flight into terrain (CFIT)
    - loss of control
    - inadequate performance capability for phase of flight, including
        - loss of obstacle clearance capability
        - exceeding takeoff or landing field length
    - exceeding the flight envelope
    - exceeding the structural integrity of the airplane
    - exciting structural modes.
- Effects on the flight crew's ability to control the engines, such as
    - those effects resulting in shutting down a non-failed engine in response to failure of a different engine
    - undetected, significant thrust loss
- Effects on the flight crew's management of the aircraft systems
- Effects on the flight crew's performance, workload and ability to cope with adverse operating conditions
- Effects on situation awareness (e.g. related to navigation, system status)

When the display system is used as a control device for other airplane systems, assessment of the failure of the display system as a control device has to consider the cumulative effect on all the controlled systems.

6.3 Failure Condition – Mitigation

When determining the mitigation means and the resulting severity of a Failure Condition, the following may be considered:

- Fault isolation and reconfiguration
- Redundancy (e.g. heading information may be provided by an independent integrated standby and/or a magnetic direction indicator)
- Availability of, level of, and type of alerting provided to the flight crew
- The flight phase and the aircraft configuration
- The duration of the condition
- The aircraft motion cues that may be used by the flight crew for recognition
- Expected flight crew corrective action on detection of the failure, and/or operational procedures
- Ability of the flight crew to control the airplane after a loss of primary attitude display on one side in some flight phases
- For multiple failures (e.g. primary and standby) the non-simultaneity of the failures
- Protections from other systems (flight envelope protection, augmentation systems)

Mitigation means should be described in the Safety Analysis/Assessment document or by reference to another document (e.g., a System Description document).

Note: Means to assure continued performance of any system design mitigation means should be identified.

The safety assessment should include the rationale and coverage of the Display System protection and monitoring philosophies employed. The safety assessment should include an appropriate evaluation of each of the identified Display System Failure Conditions and an analysis of the exposure to common mode/cause or cascade failures in accordance with AMC/ACJ 25.1309. Additionally, the safety assessment should include justification and description of any functional partitioning schemes employed to reduce the effect/likelihood of failures of integrated components or functions.

6.4 Validation of the Classification of Failure Conditions and their effects

There may be situations where the severity of the effect of a failure condition identified in the safety analysis needs to be confirmed. Laboratory, simulator or flight test, as appropriate, may accomplish the confirmation.

The method of validating the classification of Failure Conditions will depend on the effect of the condition, assumptions made and any associated risk. The severity of some Failure Conditions may be easily determined while other conditions may be somewhat difficult to determine, in particular when there is uncertainty on the likelihood of the crew to detect failures not detected by the systems. If flight crew action is expected to cope with the effect of a Failure Condition, the information available to the flight crew should be useable for detection of the failure condition and to initiate corrective action.

6.5 Safety - design guidelines

In order to provide acceptable criteria when establishing the display system safety analysis required by CFR 14/CS 25.1309 (and indirectly by other paragraphs such as 25.901, 25.903, and 25.1333), this section provides examples of generally accepted display system failure conditions together with their associated safety objectives for some typical display parameters. These examples of failure conditions should therefore not be considered an exhaustive list. Some display system designs may result in additional or different operational effects, failure conditions or different safety objectives, as determined by the system safety analysis. For example, the applicant should also identify Failure Conditions

addressing the loss of the Display Units (e.g. PFD, ND) and the cumulative effect of multiple information loss.
.
More general Display System design guidelines to contribute to the acceptable Safety level are also provided in this section.

This list is based on the experience of past certification programs but the list of failure conditions to be considered in the display system safety analysis and the associated safety objective will depend on

- The full set of functions of display system
- Display system architecture and design philosophy (e.g. failure detection, redundancy management, failure annunciation, etc..)

Safety objectives identified in the following sub-sections were determined in past certification programs on the basis of conventional display systems. Future display system design may result in different failure conditions classification and associated safety objectives.

The following failure conditions are based on the hypothesis of a generic cockpit design that includes two primary displays and one standby display.

(1) Attitude (pitch and roll)

Examples of generally accepted safety objectives for attitude related failure conditions:

Failure Condition	**Safety objective**
Loss of all attitude display, including standby display	Extremely Improbable
Loss of all primary attitude display	Remote
Display of misleading attitude information on both primary displays	Extremely Improbable
Display of misleading attitude information on one primary display	Extremely Remote
Display of misleading attitude information on the standby display	Remote (1)
Display of misleading attitude information on one primary display combined with a standby failure (loss of attitude or incorrect attitude)	Extremely Improbable (2)

(1) In the absence of mitigation supported by the System Safety Assessment for the total flight deck display system
(2) Consistent with the Safety Objective of the “Loss of all attitude display, including standby display” since the crew may not be able to sort out the correct display.
Consideration will be given to the ability of the crew to control the airplane after a loss of attitude primary display on one side in some flight phases (e.g. during takeoff).

(2) Airspeed

Examples of generally accepted safety objectives for airspeed related failure conditions:

Failure Condition	**Safety objective**
Loss of all airspeed display, including standby display	Extremely Improbable
Loss of all primary airspeed display	Remote
Display of misleading airspeed information on both primary displays, coupled with loss of stall warning or loss of over-speed warning	Extremely Improbable

Display of misleading airspeed information on the standby display	Remote (1)
Display of misleading airspeed information on one primary display combined with a standby failure(loss of airspeed or incorrect airspeed)	Extremely Improbable (2)

(1) In the absence of mitigation supported by the System Safety Assessment for the total flight deck display system
(2) Consistent with the Safety Objective of the “Loss of all airspeed display, including standby display” since the crew may not be able to sort out the correct display.

(3) Barometric Altitude

Examples of generally accepted safety objectives for altitude related failure conditions:

Failure Condition	Safety objective
Loss of all barometric altitude display, including standby display	Extremely Improbable
Loss of all barometric altitude primary display	Remote
Display of misleading barometric altitude information on both primary displays.	Extremely Improbable
Display of misleading barometric altitude information on the standby display	Remote (1)
Display of misleading barometric altitude information on one primary display combined with a standby failure (loss of altitude or incorrect altitude)	Extremely Improbable (2)

(1) In the absence of mitigation supported by the System Safety Assessment for the total flight deck display system
(2) Consistent with the Safety Objective of the “Loss of all barometric altitude display, including standby display” since the crew may not be able to sort out the correct display.
Consideration should be given that barometric setting function design is commensurate with the safety objectives identified for barometric altitude.

(4) Heading

Examples of generally accepted safety objectives for heading related failure conditions:

Failure Condition	Safety objective
Loss of stabilized heading in the cockpit	Remote (1)
Loss of all heading information in the cockpit	Extremely Improbable
Display of misleading heading information on both pilots' primary displays	Remote (1)
Display of misleading heading information on one primary display combined with a standby failure (loss of heading or incorrect heading)	Remote (1)(2)

(1) This assumes the availability of independent non-stabilized heading required by 25.1303 (a)(3)
(2) Consistent with the Safety Objective of the “Loss of all stabilized heading in the cockpit”

Standby heading may be provided by an independent integrated standby or the Magnetic direction indicator.

The safety objectives listed above can be alleviated if it can be demonstrated that track information is available and correct.

(5) Navigation and Communication (excluding heading, airspeed, and clock data)

Examples of generally accepted safety objectives for navigation and communication related failure conditions:

Failure Condition	**Safety objective**
Loss of display of all navigation information	Remote
Loss of display of all navigation information coupled with total loss of communication functions	Extremely Improbable
Display of misleading navigation information simultaneously to both pilots	Remote – Extremely Remote (1)
Loss of all communication functions	Remote

(1) The navigation information may have a safety objective which is higher than remote, based upon specific operational requirements.

(6) Other parameters (typically provided on Electronic Display Systems)

Examples of generally accepted safety objectives for other related failure conditions:

Failure Condition	**Safety objective**
Display of misleading Flight Path Vector information on one side	Remote (1)
Loss of all Vertical Speed display	Remote
Display of misleading Vertical Speed information to both pilots	Remote
Loss of all slip/skid indication display	Remote
Display of misleading Slip/Skid indication to both pilots	Remote
Display of misleading weather radar information	Remote (2)
Total loss of crew alerting display	Remote (3)
Display of misleading crew alerting information	Remote (3)
Display of misleading flight crew procedures Loss of the standby displays	Remote Remote (4)

(1) The safety objective may be more stringent depending on the use and on the flight phase
(2) Applicable to the display part of the system only
(3) See also AMC 25.1322
(4) 10E-4/flight hour is the minimum reliability level for the crew to have confidence in the standby display and to be able to rely on it when needed.

.
(7) Engine
Examples of generally accepted safety objectives for engine related failure conditions:
:
The term “required engine indications” refers specifically to the engine thrust/power setting parameter (e.g. Engine Pressure Ratio, fan speed, torque) and any other engine indications that may be required by the flight crew to maintain the engine within safe operating limits (e.g. rotor speeds, Exhaust Gas Temperature).

This table assumes the display failure occurs while operating in an autonomous engine control mode. Autonomous engine control modes, such as those provided by Full Authority Digital Engine Controls (FADECs), protect continued safe operation of the engine at any thrust lever setting. Hence, the flight deck indications and associated flight crew actions are not the primary means of protecting safe engine operation.

Failure Condition	Safety objective
Loss of one or more required engine indications on a single engine	Remote
Display of misleading display of one or more required engine indications on a single engine.	Remote
Loss of one or more required engine indications on more than one engine.	Remote
Display of misleading display of any required engine indications on more than one engine	Extremely Remote

(8) Use of Display Systems as controls

Failure Condition
Total loss of capability to use display system as a control
Undetected erroneous input from the display system as a control

Safety objectives are not provided for these failure conditions because they are dependant on the functions/systems being controlled and on alternative means of control.

Use of display systems as controls is described in Section 9.

(9) General Safety Design guidelines

Experience from previous certification has shown that a single failure which would induce misleading display of primary flight information may have negative safety effects. It is therefore recommended that the Display System design and architecture implements monitoring of the primary flight information in order to reduce the probability of displaying misleading information

Experience from previous certification has shown that combined failure of the primary display and the standby system (ref AMC 25.1333) can result in Failure Conditions with catastrophic effects.
When an Integrated Standby Display (ISD) is used to provide a backup means of primary flight information, the safety analysis should substantiate that the resulting potential for common cause failures has been addressed adequately in the design, including the design of software and complex hardware. In particular the safety analysis should show that the independence between the primary instruments and the integrated standby instruments is not violated because the ISD may interface with a large number of airplane resources, including power supplies, pitot/static ports and other sensors.

There should be a means to detect lost or erroneous primary flight information, either as a result of a display system failure or a failure of the associated sensor. This means should be sufficient to ensure that the lost or erroneous information is not useable by the flight crew (e.g. removal of the information, “X” through the failed display).

There should be a means to detect and provide immediate awareness of conflicting attitude, altitude, and airspeed information between the captain and the first officer.

(10) Development Assurance guidelines for window management

For those systems that integrate windowing architecture into the display system a means should be provided to control the information shown on the displays, such that the integrity of the display system as a whole will not be adversely impacted by anomalies in the functions being integrated.
This means of controlling the display of information, called window manager hereafter, should be developed to the development assurance level (DAL) at least as high as the highest integrity function of any window. For example, a window manager should be level A if the information displayed in any window is level A. ARP4754, “Certification Considerations For Highly-Integrated or Complex Aircraft Systems” or its latest edition, provides a recommended practice that may be used to perform development assurance.

7 Display Information Elements and Features

This section provides guidance for the display of information elements including text, labels, symbols, graphics and other depictions (such as schematics) in isolation and in combination. It covers the design and formatting of these information elements within a given display area. Section 8 covers the integration of information across several display areas across the flight deck, including guidance on flight deck information location, display arrangement, windowing, redundancy management, and failure management.

7.1 General

General objectives for each display information element, in accordance with its intended function:

- It should be easily and clearly discernable, and have enough visual contrast for the pilot to see and interpret it.
- All probable lighting conditions should be considered for all display configurations including failure modes such as lighting and power system failures. This includes the full range of flight deck lighting options, day and night operations (per 25.773(a)) and 25.1321(e), and display system lighting options.
- Information elements (text, symbol, etc.) should be large enough to see and interpret in all foreseeable operating conditions.
- Overall, the display should allow the pilot to identify and discriminate the information without eyestrain.
- The pilots should have a clear and undistorted view of the displayed information (25.773(a)(1)). (move to section 5.2 "Display hardware installation" and fold in appropriate parts of the text below)

Factors to consider when designing and evaluating the viewability of the displayed information include:

- *Position* of *displayed information*: Distance from the Design Eye Position (DEP) is generally used. If cross-flight deck viewing of the information is needed, distance from the offside DEP, accounting for normal head movement, should be used. For displays not mounted on the front panel, the distance determination should include any expected movement off the DEP by the flight crewmember.
- Vibrations: Viewability should be maintained in adverse conditions, such as vibration (as defined in AC 25-24).

7.2 Consistency

Display information should be presented consistent with the flight deck design philosophy in terms of location, control, behavior, size, shape, color, labeling, and alerting. Consistency implies a common standard of use and equivalent look and feel, in accordance with the overall flight deck design philosophy. In addition to symbology, the color, shape, dynamics and other symbol characteristics representing the same function on more than one display on the same flight deck should be consistent. Acronyms should be used consistently, and messages/annunciations should contain text in a consistent way. Inconsistencies should be evaluated to ensure that they are not susceptible to confusion, errors, and do not adversely impact the intended function of the system(s) involved.

Consistent positioning may be accomplished by always putting the information in the same location or by keeping the position consistent relative to some other information on the display.

The following information should be in a consistent position:

- Autopilot and flight director modes of operation
- Failure flags. (Where appropriate, flags should appear in the area where the data is normally placed)

The following information should be placed in the same relative position whenever shown: [Need to re-write for consistency, clarity, and to ensure that the “relative to what” is specified]

- Real time sensor data (e.g. localizer deviation, radio altitude, traffic), airplane position, and menus
- Airplane system information (relative to actual airplane position <u>and</u> to other graphics for that system) such as propulsion indications
- Map features (relative to current position)
- Failure flags (relative to the indications they replace)
- Segment of flight information (relative to similar information for other segments)
- Bugs, limits and associated data (relative to the information they support) such as tape markings
- Data messages (relative to other related messages) such as crew alerts or data links
- Image reference point, unless the flight crew takes action to alter the reference point

  When a control or indication occurs in multiple places (e.g. a “Return” control on multiple pages of a Flight Management function), the control or indication should be located consistently for all occurrences

7.3 Display Information Elements

(1) Text
This section contains general guidance on all text used in the flight deck, including labels and messages.

Text should be shown to be distinct and meaningful for the information presented. Messages should convey the meaning intended. Abbreviations and acronyms should be clear and consistent with established standards. For example, ICAO 8400/5 provides internationally recognized standard abbreviations and airport identifiers.

Regardless of the font type, font size, color, and background, text should be readable in all of the conditions specified above. General guidelines for text are as follows:

- Standard grammatical use of lower and upper case fonts for lengthy documentation and lengthy messages
- All upper case letters for text labels are acceptable.
- The use of contractions, such as “can’t” instead of “can not,” is not recommended
- Lines of text should be broken only at spaces or other natural delimiters
- The use of excessive abbreviations and acronyms should be minimized
- Generally, ARP 4102-7 provides guidelines on font sizes that have found to be acceptable. For displays close to the DEP, larger fonts may be desirable to accommodate flight crewmembers who have difficulty focusing up close (far-sighted).

The choice of font also affects readability. The following guidelines apply:

- The font chosen should be compatible with the display technology to facilitate readability. For example, serif fonts may become distorted on some low pixel resolution displays. However, on displays where serif fonts have been found acceptable, they have been found to be useful for depicting full sentences or larger text strings.
- Sans serif fonts (e.g., Futura or Helvetica) are recommended for displays viewed under extreme lighting conditions.

(2) Labeling
This section contains guidance on labeling items such as knobs, buttons, symbols, and menus. Labels may be text or icons. The guidance in this section applies to labels that are on the display, or which label the display, or the display controls. Regulation 14 C.F.R. § 25.1555(a) requires that each flight deck control, other than controls whose function is obvious, must be plainly marked as to its function and

method of operation. For a control function to be considered obvious, a crewmember with little or no familiarity with the aircraft should be able to rapidly, accurately and consistently identify all of the control functions.

Text and icons should be shown to be distinct and meaningful for the function(s) they label. Standard or non-ambiguous symbols, abbreviations, and nomenclature should be used.

If a control performs more than one function, labeling should include all intended functions unless the function of the control is obvious. Labels of graphical controls accessed via a cursor control device should be included on the graphical display.

When using icons instead of text labeling, only brief exposure to the icon should be needed in order for the flight crew to determine the function and method of operation of a control. The use of icons should not cause significant flight crewmember confusion.

The following are guidelines and recommendations for labels.
- Data fields should be uniquely identified either with the unit of measurement or a descriptive label. However, some basic “T” instruments have been found to be acceptable without units of measurement.
- Labels should be consistent with related labels located elsewhere in the flight deck.
- When a control or indication occurs in multiple places (e.g. a “Return” control on multiple pages of a Flight Management function), the label should be consistent across all occurrences

Labels should be placed such that:
- The spatial relationships between labels and the objects they reference should be unambiguous.
- Labels for display controls should be on or adjacent to the controls they identify.
- Control labels should not be obstructed by the associated controls
- Labels should be oriented to facilitate readability. (e.g. continuously maintain an upright orientation or align with associated symbol such as runway or airway).
- On multi-function displays a label should be used to indicate the active function(s), unless it’s function is obvious. When the function is no longer active or being displayed the label should be removed unless another means of showing availability of that function is used (e.g. graying out an inactive menu button).

(3) Symbols
This section provides guidance related to flight deck symbols.

Symbol appearance and dynamics should be designed to enhance flight crew comprehension, retention, and minimize crew workload and errors in accordance with the intended function.
- Symbols should be positioned with sufficient accuracy to avoid interpretation error or significantly increased interpretation time.
- Each symbol used should be identifiable and distinguishable from other related symbols.
- The shape, dynamics, and other symbol characteristics representing the same function on more than one display on the same flight deck should be consistent.
- Within the flight deck, using the same symbol for different purposes increases the likelihood of interpretation errors and increases training times and therefore should be avoided.

It is recommended that standardized symbols be used. The symbols in the following documents have been found to be acceptable: SAE ARP 4102/7 Appendix A-C (for primary flight, navigation, and powerplant displays), SAE ARP 5289 (for depiction of navigation symbology) and SAE-ARP 5288 (for HUD symbology).

(4) Display Indications

This section contains guidance on numeric readouts, gauges, scales, tapes and graphical depictions such as schematics. Graphics related to interactivity are discussed in section 9.

The following are general guidelines and apply to all graphics and display indications:

- They should be readily understood and compatible with other graphics and indications in the flight deck. Additionally they should be identifiable and readily distinguishable.
- Guidance for viewability, text and legends in the sections above apply to graphic elements and display indications as well.

(5) Numeric Readouts

Numeric readouts include displays that emulate rotating drum readouts where the numbers scroll, as well as displays where the digit locations stay fixed.

Data accuracy of the numeric readout should be sufficient for the intended function and to avoid inappropriate crew response. The number of significant digits should be appropriate to the data accuracy. Leading zeroes should not be displayed unless convention dictates otherwise. As the digits change or scroll, there should not be any confusing motion effects such that the apparent motion does not match the actual trend.

When a numeric readout is not associated with any scale, tape, or pointer, it may be difficult for pilots to determine the margin relative to targets or limits, or compare between numeric parameters. A scale, dial or tape may be needed to accomplish the intended crew task.

Numeric readouts of heading should indicate 360, as opposed to 000, for North.

(6) Scales, Dials, and Tapes

Scales, dials and tapes with fixed or moving pointers have been shown to effectively improve crew interpretation of numeric data,

The displayed range should be sufficient to perform the intended function. If the entire operational range is not shown at any given time, the transition to the other portions of the range should not be distracting or confusing.

Scale resolution should be sufficient to perform the intended task. They may be used without an associated numeric readout if alone they provide sufficient accuracy for the intended function. When numeric readouts are used in conjunction with scales, tapes or dials, they should be located close enough to ensure proper association yet not detract from the interpretation of the graphic or the readout.

Delimiters such as tick marks should allow rapid interpretation without adding unnecessary clutter. Markings and labels should be positioned such that their meaning is clear yet they do not hinder interpretation. Pointers and indexes should be unambiguous and readily identifiable. They should not obscure the scales or delimiters such that they can no longer be interpreted. They should be positioned with sufficient accuracy at all times. Accuracy includes effects due to data resolution, latency, graphical positioning, etc.

(7) Other Graphical Depictions

Depictions include schematics, synoptics, and other graphic depictions such as attitude indications, moving maps, and vertical situation displays.

To avoid visual clutter, graphic elements should be included only if they add useful information content, reduce flight crew access or interpretation time, or decrease the probability of interpretation error.

To the extent it is practical and necessary, the graphic orientation and the flight crews' frame of reference should be correlated. For example, left indications should be on the left side of the graphic and higher altitudes should be shown above lower altitudes..

Graphics that include three-dimensional effects should ensure the symbol elements being used to achieve these effects would not be interpreted as information in and of themselves.

(8) Use of Color
This sub-section provides guidance on the use of color.

When color is used for coding, at least one other distinctive coding parameter should be used (e.g., size, shape, location, etc.).

Color standardization is highly desirable, to ensure correct information transfer, and is required for the use of red and amber/yellow per 25.1322.Colors used for one purpose in one information set should not be used for another purpose within another information set. To avoid confusion or interpretation error, there should be no change in how the color is perceived over the range of operating conditions.
If the color coding does not represent the outside world (e.g. weather radar depictions), it should not conflict with pilots' inherent understanding of the meaning of the colors used.

The use of no more than six colors for coding is considered good practice. Each coded color should have sufficient chrominance separation such that it is identifiable and distinguishable in all foreseeable operating conditions and when used with other colors. Colors should be identifiable and distinguishable across the range of information element size, shape, and movement. The colors available for coding from an electronic display system should be carefully selected to maximize their chrominance separation.

The following table depicts previously accepted colors related to their functional meaning recommended for electronic display systems with color displays.

Feature	Color
Warnings*	Red
Flight envelope and system limits, exceedances*	Red or Yellow/Amber as appropriate (see above)
Cautions, non-normal sources*	Yellow/amber
Scales, dials, tapes, and associated information elements	White
Earth	Tan/brown
Sky	Blue/Cyan
Engaged Modes/normal conditions	Green
ILS deviation pointer	Magenta

* Reference to AC 25-1322.

When background color is used (e.g. Grey),it should not impair the use of the overlaid information elements. Labels, display-based controls, menus, symbols, and graphics should all remain identifiable and distinguishable. The use of background color should conform to the overall flight deck philosophies for color usage and information management. If texturing is used for a background, it should not result in loss of readability of the symbols overlaid on it, nor should it increase visual clutter or pilot information access time. Transparency is a means of seeing a background information element through a foreground one – the use of transparency should be minimized because it may increase pilot interpretation time or errors.

Requiring the flight crew to discriminate between shades of the same color for distinct meaning is not recommended. The use of pure blue should not be used for important information because it has low luminance on many display technologies (e.g. CRT, LCD).

Any foreseeable change in symbol size should ensure correct color interpretation.

7.4 Dynamic Information

This section covers the motion of graphic information elements on a display, such as the indices on a tape display.

Graphic objects that translate or rotate should do so smoothly without distracting or objectionable jitter, jerkiness, or ratcheting effects. Data update rates for information elements used in direct airplane or powerplant manual control tasks (such as attitude, engine parameters, etc.) equal to or greater than 15 hertz have been found to be acceptable. Any lag introduced by the display system should be consistent with the airplane control task associated with that parameter. In particular, display system lag (including the sensor) for attitude which does not exceed a first order equivalent time constant of 100 milliseconds for airplanes with conventional control system response has been found to be acceptable.

Movement of display information elements should not blur or shimmer or produce unintended dynamic effects such that the image becomes distracting or difficult to interpret. Filtering or coasting of data intended to smooth the motion of display elements should not introduce significant positioning errors or create system lag that makes it difficult to perform the intended task.

When a symbol reaches the limit of its allowed range of motion, the symbol should either slide from view or change visual characteristics to clearly indicate that it has reached a fixed limit condition.

Dynamic information should not appreciably change shape or color as it moves. .
Objects that change sizes (e.g. as the map range is changed) should not cause confusion as to their meaning and remain consistent throughout their size range. At all sizes the objects should meet the guidance of this section as applicable (discernable, legible, identifiable, accuracy of placement, not distracting, etc.)

7.5 Sharing Information on a Display

There are three methods of sharing information on a given display. First, the information may be overlayed or combined, such as when TCAS information is overlayed on a map display. Second, the information can be time shared so that the pilot toggles between functions, one at a time. Third, the information may displayed in separate physical areas or windows that are concurrently displayed.

(1) Overlays and Combined Information Elements
The following guidelines apply:

- When information elements interact or share the same location on a display, the loss of information availability, information access times, and potential for confusion should be minimized.
- When information obscures other information – it should be shown that the obscured information is either not needed, or can be recovered. Needed information should not be covered. This may be accomplished by protecting certain areas of the display.
- If information, such as traffic or weather, is integrated with other information (such as the navigation information) on a display, the projection, the placement accuracy, the directional orientation and the display data ranges should all be consistent. When information elements temporarily obscure other information (e.g. pop-up menus or windows), the resultant loss of information should not cause a hazard in accordance with the obscured information's intended

function. Care should be taken to ensure the information being out-prioritized will not be needed more quickly than it can be recovered, if it can be recovered at all.

(2) Time Sharing
Guidance relating to time sharing information:

- Any information that should or must be continuously monitored by the flight crew (e.g., attitude) should be displayed at all times.
- Whether information may be time shared or not will depend on how easily it can be retrieved Information for a given performance monitoring task may be time shared if the method of switching back and forth does not jeopardize the performance monitoring task.
- System information, planning, and other information not necessary for the pilot tasks can generally be time shared.
- Care should be taken to ensure the information being out-prioritized will not be needed more quickly than it can be recovered, if it can be recovered at all.

(3) Separating Information
When different information elements are adjacent to each other on a display, there should be sufficient visual separation such that the pilots can easily distinguish between them. Visual separation can be achieved with spacing, delimiters or shading in accordance with the overall flight deck information management philosophy. Required information presented in reversionary or compacted display modes following a display failure should still be uncluttered and not drastically increase information access time.

(4) Clutter and De-Clutter
A cluttered display is one which presents an excessive number and/or variety of symbols, colours, or other information. This causes increased flight crew processing time for display interpretation, and may detract from the interpretation of information necessary for the primary tasks.

Declutter of unnecessary data may be considered to enhance the pilot's performance in certain conditions (e.g. de-selection of automatic pilot engaged mode annunciation and flight director in extreme attitudes).

7.6 Annunciations and Indications

Annunciations and indications include annunciator switches, messages, prompts, flags, status or mode indications which are either on the flight deck display itself, or control a flight deck display.

Additional guidance for crew alerting is provided in AC/AMC 25-1322.

Annunciations and indications should be operationally relevant and limited to minimize the adverse effects on flight crew workload.

Annunciations and indications should be clear, unambiguous, and consistent with the flight deck design philosophy. When annunciation is provided for the status or mode of a system, it is recommended that the annunciation indicates the actual state of the system and not just switch position or selection. Annunciations should only be indicated while the condition exists.

(5) Location of Annunciations and Indications
Annunciations and indications should also be consistently located in a specific area of the electronic display. Annunciations that may require immediate flight crew awareness should be located in the flight crew's forward/primary field of view.

(6) Managing of Messages and Prompts
The following guidance applies to all messages and prompts:

- There should be an indication if there are additional messages that are in a message queue that are not being displayed.

- Within levels of urgency, messages should be displayed in logical order.
- If the length of the information for the message, prompt, or response options is not displayed on the a single page, there should be an indication that additional information exists.

The following contains general guidance on selecting the type of attention getting cue:

- A text change by itself is typically inadequate to annunciate automatic or uncommanded mode changes.

Blinking information elements such as readouts or pointers has been shown to be an effective annunciation. However, the use of blinking should be limited as it can be distracting and excessive use reduces the attention getting effectiveness. Blinking rates between .8 and 4 Hz should b used, depending on the display technology and the compromise between urgency and discomfort. If blinking of an information element can occur for more than approximately 10 seconds, a means to cancel the blinking should be provided.

7.7 Use of Imaging

This section covers the use of images, which depict a specific portion of the airplane environment. Images may be static or continuously evolving. Imaging includes weather radar returns, terrain depictions, forecast weather maps, video, enhanced vision displays and synthetic vision displays. Images may be generated from databases or by sensors.

Images should be of sufficient size and include sufficient detail to meet the intended function. The pilots should be able to readily distinguish the features depicted. Images should be oriented in such a way that their presentation is easily interpreted. All images, but especially dynamic images, should be located or controllable such that they do not distract the pilots from required tasks. The control, coloring, labeling, projection and dynamics of images throughout the flight deck should be consistent. The source and utility of the image and the level of operational approval for use of the image should be available to the pilots. This can be accomplished using the airplane flight manual, image location, adequate labeling, distinct texturing or other means.

Image distortion should not compromise image interpretation. Images meant to provide information about depth (i.e. 3D) should provide adequate depth information to meet the intended function.

Dynamic images should meet the guidance in sub-section 7.3 above. The overall system lag time of a dynamic image relative to real time should not cause crew misinterpretation or lead to a potentially hazardous condition. Image failure, freezing or coasting should not be misleading and should be considered during the safety analysis.

When overlaying coded information elements over images, the information elements should be readily identifiable and distinguishable. The information elements should not obscure necessary information contained in the image. They should be placed with sufficient accuracy to avoid being misleading. They should retain and maintain their shape, size and color for all foreseeable conditions of the underlying image and range of motion.

When fusing or overlaying multiple images, the resultant combined image should meet its intended function despite any differences in image quality, projection, data update rates, sensitivity to sunlight, data latency or sensor alignment algorithms. When conforming an image to the outside world, such as on a HUD, the image should not obscure or significantly hinder the flight crew's ability to detect real world objects. An independent brightness control of the image may satisfy this guideline. Image elements that correlate or highlight real world objects should be sufficiently coincident to avoid interpretation error or significantly increase interpretation time.

8 Organization of Information Elements

8.1 General

This section provides guidance concerning integration of information into the flight deck related to managing the location of information, display arrangement (such as Basic T), windowing, display reconfiguration, and sensor selection across the flight deck displays. Section 7 covers the information elements including: text, labels, symbols, graphics and other depictions (such as video) in isolation and combination.

This section will cover the various flight deck configurations from dedicated electronic displays for ADI and HSI to larger display sizes which use windowing techniques to display various functionalities, such as PFI and ND or more, on one display area. This section also provides guidance for managing display configuration.

8.2 Types and Arrangement of Display Information

This section provides guidance for the arrangement and location of categories of information. The categories of information include:

1. Primary Flight Information (PFI) including attitude, airspeed, altitude and heading.
2. Powerplant Information (PI) which covers functions relating to propulsion.
3. Other Information

The position of a message or symbol within a display converys meaning to the pilot. Without the consistent or repeatable location of a symbol in a specific area of the electronic display, interpretation error and response times may increase. The following information should be placed in a consistent location under normal (i.e. no display failure) conditions:

- Crew alerts – each crew alert should be displayed in a specific location or a central crew alert area
- Autopilot and flight director modes of operation
- Lateral and vertical path deviation indicators
- Radio altitude indications

The following information should be displayed in a consistent relative location:

- Failure flags should be presented in the location of the information they reference or replace
- Data labels for navigation, traffic, airplane system and other information should be placed in a consistent position relative to the information they are labeling
- Airplane system information, relative to related displayed information
- Supporting data for other information such as bugs and limit markings should be consistently positioned relative to the information they support.

(1) Basic T Information

Regulation 25.1321(b) includes requirements for the “Basic T” arrangement of certain information required by 25.1303(b): attitude, airspeed, altitude, and direction.. This sub-section provides guidance for the presentation of this information. It applies whether the information is displayed on one display surface or spread across multiple display surfaces.

The Basic T information should be displayed continuously, directly in front of each flight crew member under normal (i.e. no display system failure) conditions.

The Basic T arrangement applies to the primary display of attitude, airspeed, altitude and direction of flight. Depending on the flight deck design, there may be more than one indication of the Basic T information elements, such as heading, in front of a pilot (e.g. back-up displays, HUD, or moving map displays). In this case, primary attitude is the attitude reference located most directly in front of the pilot and operationally designated as the primary attitude reference. The primary airspeed, altitude and direction indications are the respective display indications closest to the primary attitude indication.

The primary attitude indication should be centered as nearly as practicable about the plane of the flight crew's forward vision. This should be measured from the Design Eye Position. If located on the main instrument panel, the primary attitude indication must be in the top center position (25.1321b). . The attitude indication should be placed such that the display is unobstructed under all flight conditions. Refer to ARP 4102/7 for additional information.
The primary airspeed, altitude and direction of flight indications should be located adjacent to the primary attitude indication. Display information placed within, overlaid, or between these indications such as lateral and vertical deviation, has been found to be acceptable when it is relevant to completing the basic flying task and is shown to not disrupt the normal crosscheck or decrease manual flying performance.

The instrument that most effectively indicates airspeed must be adjacent to and directly to the left of the primary attitude indication (25.1321b). The center of the airspeed indication should be aligned with the center of the attitude indication. For round dial airspeed indications, deviations vertically have been found acceptable up to one inch below or above the direct horizontal position. For tape type airspeed indications, the center of the indication is defined as the center of the current airspeed status reference. Deviations have been found acceptable up to 15 degrees below and 10 degrees above the direct horizontal position as referenced to the attitude indication.

Parameters related to the primary airspeed indication, such as reference speeds or a mach indication, should be displayed to the left of the primary attitude indication.

The instrument that most effectively indicates altitude must be located adjacent to and directly to the right of the primary attitude indication (25.1321b). The center of the altitude indication should be aligned with the center of the attitude indication. For round dial altitude indications, deviations vertically have been found acceptable up to one inch below or above the direct horizontal position. For tape type altitude indications, the center of the indication is defined as the center of the current altitude status reference. Deviations have been found acceptable up to 15 degrees below and 10 degrees above the direct horizontal position.

Parameters related to the primary altitude indication, such as the barometric setting or the primary vertical speed indication, should be displayed to the right of the primary attitude indication.

The instrument that most effectively indicates direction of flight must be located adjacent to and directly below the primary attitude indication (25.1321b). The center of the direction of flight indication should be aligned with the center of the attitude indication. The center of the direction of flight indication is defined as the center of the current direction of flight status reference.

Parameters related to the primary direction of flight indication, such as the reference (i.e. magnetic or true) or the localizer deviation should be displayed below the primary attitude indication.

Any deviation from 25.1321b, as by equivalent safety findings, can not be granted without human factors substantiation which may include well-founded research, or relevant service experience from military, foreign, or other sources.

(2) Powerplant Information

This section provides guidance for location and arrangement of required powerplant information.

Parameters necessary to set and monitor engine thrust or power should be continuously displayed in the flight crew's primary field of view unless the applicant can demonstrate that this is not necessary (see Appendix B). The automatic or manually selected display of powerplant information should not suppress other information that requires flight crew awareness.

Powerplant information must be closely grouped (in accordance with 25.1321) in an easily identifiable and logical arrangement which allows the flight crew to clearly and quickly identify the displayed information and associate it with the corresponding engine. Typically, it is considered to be acceptable to arrange parameters related to one powerplant in a vertical manner and, according to powerplant position, next to the parameters related to another powerplant in such a way that identical powerplant parameters are horizontally aligned. Generally, place parameter indications in order of importance with the most important at the top.

(3) Other Information

Glideslope deviation scales should be located to the right side of the primary attitude indication. If glideslope deviation data is presented on both an EHSI and an EADI, they should be on the same side.

Information such as navigation information, weather, and vertical situation display is often displayed on Multi-Function Displays (MFD) which may be displayed on one or more physical electronic displays or on areas of a larger display. When this information is not required to be displayed continuously, it can be displayed part-time.

Other Information should not be located where the PFI or required PI is normally presented.

8.3 Managing Display Information

This section addresses managing and integrating the display of information across the flight deck. This includes the use of windowing on a display area to present information and the use of menuing to manage the display of information.

(1) Window
A window is a defined area which can be present on one or more physical displays. A window that contains a set of related information is commonly referred to as a format. Multiple windows may be presented on one physical display surface and may have different sizes. Guidelines for sharing information on a display, using separate windows, are as follows:

- It is recommended that the window(s) have fixed size(s) and location(s).
- The window size and location should be defined for normal and non-normal conditions.
- Separation between information elements should be sufficient to allow the flight crew to readily distinguish separate functions or functional groups (e.g. powerplant indication) and avoid any distractions or unintended interaction.
- Display of flight crew selectable information such as a window on a display area should not interfere with or affect the use of primary flight information.
- See also ARINC 661 for display of data on a given location, data blending, and data over-writing.

(2) Menu
A menu is a displayed list of items from which the flight crewmember can choose. Examples of menus used in electronic display systems include drop-down menus, and scrolling menus. An option is one of the selectable items in a menu. Selection is the action a user makes in choosing a menu option, and may be done by, pointing (with a cursor control device or other mechanism), by entry of an associated option code, or by activation of a function key.

Menu structure is the organization of options into individual menus and their hierarchical relationship. The menu structure should be designed to allow flight crewmembers to sequentially step through the available menus or options in a logical way that supports their tasks. For the grouping of options into individual menus, the options provided on any particular menu should be logically related to each other. Menus should be displayed in consistent locations so that the flight crew knows where to find them. The system should at all times indicate the current position within the menu.

The number of sub-menus should be designed to assure appropriate access to the desired option without over-reliance on memorization of the menu structure. The presentation of items on the menu should allow clear distinction between items that select other menus and items that are the final selection.

The number of steps required to choose the desired option should be consistent with the frequency, importance and urgency of the flight crew's task.

Menus should minimize obscuration of the presentation of required information while a menu is displayed.

(3) Full-time vs. Part-time Displays
Some airplane parameters or status indications are required to be displayed (e.g. 25.1305), yet they may only be necessary or required in certain phases of flight. If it is desired to inhibit some parameters from a full-time display, an equivalent level of safety to full-time display should be demonstrated. Criteria to be considered include the following:

- Continuous display of the parameter is not required for safety of flight in all normal flight phases.
- The parameter is automatically displayed in flight phases where it is required.
- The inhibited parameter is automatically displayed when its value indicates an abnormal condition.
- Display of the inhibited parameter can be manually selected by the crew without interfering with the display of other required information.
- If the parameter fails to be displayed when required, the failure effect and compounding effects must meet the requirements of 25.1309.
- The automatic, or requested, display of the inhibited parameter should not create unacceptable clutter on the display; simultaneous multiple "pop-ups" should be considered.
- If the presence of the new parameter is not sufficiently self-evident, suitable alerting must accompany the automatic presentation.

(4) Pop-up/Linking
Certain types of display information such as Terrain and TCAS are required by the operating regulations to be displayed, yet they are only necessary or required in certain phases of flight or under specific conditions. One method commonly employed to display this information is called "automatic pop-up". "Automatic pop-ups" may be in the form of an overlay, such as TCAS overlaying the moving map, or in a separate window as a part of a display format. Pop-up window locations should not obscure required information. Criteria for displaying "automatic pop-up" information include the following:

- Information is automatically displayed when its value indicates a predetermined condition, or when the associated parameter reaches a predetermined value.
- Pop-up information should appropriately attract the flight crew attention.
- If the flight crew deselects the display of the "automatic pop-up" information, then another "automatic pop-up" should not occur until a new condition/event causes it.

- If an “automatic pop-up” condition is asserted and the system is in the wrong configuration or mode to display the information, and the system configuration can not be automatically changed, then an annunciation should be displayed in the color associated with the nature of the alert, prompting the flight crew to make the necessary changes for the display of the information.
- If a pop-up(s) occurs and obscures information, it should be shown that the obscured information is not relevant or necessary for the flight crew task. Additionally it should not cause a misleading presentation. Simultaneous multiple “pop-ups” should be considered.
- If more than one “automatic pop-up” occurs simultaneously on one display area, for example a Terrain and TCAS pop-up, then the system should prioritize the pop-up events based on their criticality.
- Any information to a given system that is not continuously displayed, but that the safety assessment of the system determines is necessary to be presented to the flight crew, should automatically pop-up or otherwise give an indication that its display is required.

8.4 Managing Display Configuration

This section addresses the management of the information presented by an electronic display system and its response to failure conditions and flight crew selections. It will also provide guidance on the acceptability of display formats and their required physical location on the flight deck both during normal flight and in failure modes. Manual and automatic system reconfiguration and source switching are also addressed.

(1) Managing Display Configuration in Normal Conditions
In normal conditions (i.e. non failure conditions), there may be a number of possible display configurations that may be selected manually or automatically. All possible display configurations available to the flight crew should be designed and evaluated for arrangement, visibility, and interference.

(2) Display System Reconfiguration
This section provides guidance on manual and automatic display system reconfiguration in response to display system failure. The arrangement and visibility requirements also apply in failure conditions and alternative display locations used in non-normal conditions will have to be evaluated by the Authority.

Moving display formats to different display locations on the flight deck or using redundant display paths to drive display information has been found to be acceptable to meet availability and integrity requirements.

In an instrument panel configuration with a display unit for Primary Flight Information (PFI) positioned above a display unit for navigation information, it has been found acceptable to move the PFI to the lower display unit when the upper display unit has failed.

In an instrument panel configuration with a display unit for Primary Flight Information (PFI) positioned next to a display unit for navigation information, it has been found acceptable to move the PFI to the display unit directly adjacent to it in case the preferred display unit has failed. It has been found acceptable to switch the navigation information to a centrally located auxiliary display (multifunction display).

If several possibilities exist for relocating the failed display, there should be a recommended procedure in the airplane flight manual.

It has been found acceptable to have manual or automatic switching capability in case of system failure (source, symbol generator, display unit) to ensure that required information remains available to the flight crew. In case several displays have failed, complete suppression of primary flight information may be considered for brief periods of time on a case-by-case basis, provided that the standby indication is operational and the primary flight information is readily recoverable.

The following means to reconfigure the displayed information have been found acceptable:

- Display unit reconfiguration. Moving a display format to a different location (e.g. move the PFI to adjacent display unit) or the use of a compacted format has been found acceptable.

- Source/graphic generator reconfiguration. The reconfiguration of graphic generator sources either manually or automatically to accommodate a failure has been found acceptable. In the case where both Captain and First Officer displays are driven by a single graphic generator source, there should be clear, cautionary alerting to the flight crew that the displayed information is from a single graphic generator source.

In certain flight phases, manual reconfiguration may not satisfy the need for the flying pilot to recover PFI without delay. Automatic reconfiguration might be necessary to cope with failure conditions that require immediate flight crew member action.

When automatic reconfiguration occurs (e.g. display transfer), it should not adversely affect the performance of the flight crew and should not result in any trajectory deviation.

When the display reconfiguration results in switching of sources or display paths that is not annunciated and is not obvious to the crew, care should be taken that the crew is aware of the actual status of the systems when necessary depending on flight deck philosophy.

An alert should be given when the information presented to the crew is no longer meeting the required safety level, in particular single source or loss of independence.

8.5 Methods of Reconfiguration

(1) Compacted Format
The term "compacted format," as used in this AC, refers to a reversionary display mode where selected display components of a multi-display configuration are combined in a single display format to provide higher priority information. The “compacted format” may be automatically selected in case of a primary display failure or it may be manually selected by the flight crew. The concepts and requirements of § 25.1321, as discussed in Section 8.2.1, still apply.

The compacted display format should maintain the same display attributes (color, symbol location, etc..) as the primary formats it replaces. The compacted format should ensure the proper operation of all the display functions it presents, including annunciation of navigation and guidance modes if present. Due to size constraints and to avoid clutter it may be necessary to reduce the amount of display functions on the compacted format. For example the use of numeric readouts in place of graphical scales has been found to be acceptable. Failure flags and mode annunciations should, wherever possible, be displayed in a location common with the normal format.

(2) Sensor Selection and Annunciation
Manual or automatic switching of sensor data to the display system is acceptable in the event of sensor failure.

Independent attitude, direction, and air data sources are required for the Captain and First Officer displays of Primary Flight Information (Ref 14 CFR/CS25 § 25.1333). If sources can be switched such that the Captain and First Officer are provided with single sensor information, there should be a clear annunciation indicating this vulnerability to misleading information to both flight crew members.

If sensor information sources can not be switched, then no annunciation is required.

There should be a means of determining the source of the displayed navigation information and the active navigation mode.

If multiple or different type of navigation sources (FMS, ILS, GLS, etc.) can be selected (manually or automatically), then the selected source should be annunciated.

For highly integrated display systems, automatic sensor switching is recommended to address those cases where multiple failure conditions may occur at the same time and require immediate flight crew member action.

For automatic switching of sensors that is not annunciated and is not obvious to the crew, care should be taken that the crew is aware of the actual status of the systems when necessary. An alert should be given when the information presented to the crew is no longer meeting the required integrity level, in particular when there is a single sensor or loss of independence.

9 Display Control Devices

Advances in technology have enabled displays to do more than just provide traditional information presentation. The means of interaction with the display system can be as varied as the modalities of human perception. Each of these modalities has characteristics unique to its operation that need to be considered in design of the functions it controls and the redundancy provided during failure modes. Despite the amount of redundancy that may be available to achieve a given task, the flight deck should still present a consistent user interface scheme for the primary displays and compatible, if not consistent, user interface scheme for auxiliary displays throughout the flight deck.

(1) Multifunction controls should be labeled such that the pilot is able to:

- Rapidly, accurately, and consistently identify and select all functions of the control device
- Quickly and reliably identify what item on the display is "active" as a result of cursor positioning as well as what function will be performed if the item is selected using the selector buttons and/or changed using the multifunction knob.
- Determine quickly and accurately the function of the knob without extensive training or experience.

9.1 Mechanical Controls

The installation guidelines below apply to control input devices that are dedicated to the operation of a specific function (e.g. control knobs, wheels), as well as new control features (e.g. Cursor Control Device, or CCD).

Mechanical controls (e.g knobs, wheels) used to set numeric data on a display should have adequate friction or tactile detents to allow the flight crew to set values (e.g. setting an out-of-view heading bug to a displayed number) without extensive training or experience.. Controls for this purpose should have an appropriate amount of feel to minimize the potential for inadvertent changes.

The display response gain to control input should be optimized for gross motion as well as fine positioning tasks without overshoots. The sense of motion of controls should comply with the requirements of §25.779, where applicable.

9.2 Software Controls

Display systems can range from no crew interaction to crew interaction that can affect airplane systems. Three display types are identified below.

i) <u>Display only</u>: The most common function of displays is to provide information only. This includes display technologies (e.g. CRT, LCD).There is no crew interaction involved other than perception of the display information.

ii) <u>Interactive display</u>: Displays that utilize a graphical user interface (GUI) permit information within different display areas to be directly manipulated by the crew (e.g. changing range, scrolling CAS messages or electronic checklists, configuring windows, layering information). This level of display interaction affects only the presentation of display information and has a minimal effect on flight deck operations. There is no effect on control of airplane systems.

iii) <u>Airplane system control through displays</u>: Displays that provide a GUI to control airplane systems operations (e.g., utility controls on displays traditionally found in overhead panel functions, FMS operations, graphical flight planning) are also considered "interactive". The amount of airplane control that a system provides should be compatible with, and equivalent testing required, for the level of criticality of the GUI and control device for that system. These are discussed in detail in section 9.1 below.

The design of display systems as "controls" is dependent on the functions they control, and the applicant should consider the following guidelines:

(1) Redundant methods of controlling the system may lessen the criticality required of the display control. Particular attention should be paid to the interdependence of display controls (i.e. vulnerability to common mode failures), and to the combined effects of the loss of control of multiple systems and functions.

(2) The applicant should demonstrate that the failure of any display control does not unacceptably disrupt operation of the airplane (i.e. the allocation of flight crew member tasks) in normal, non-normal and emergency conditions.

(3) To show compliance with §§ 25.777(a) and 25.1523, the applicant should show that the flight crew can conveniently access required and backup control functions in all expected flight scenarios, without unacceptable disruption of airplane control, crew task performance, and Crew Resource Management (CRM).

(4) Control system latency and gains can be important in the acceptability of a display control. Usability testing should therefore accurately replicate the latency and control gains that will be present in the actual airplane.

(5) To minimize flight crew workload and error, the initial response to a control input should take no longer than250 msec to acknowledge the input. If the initial response to a control input is not the same as the final expected response, a means of indicating the status of the pilot input should be made available to the flight crew.

(6) To show compliance with § 25.771(e)the applicant should show by test and/or demonstration in representative motion environment(s) (e.g. turbulence) that the display control is acceptable for controlling all functions that the flight crew may access during these conditions.

9.3 Cursor Control Device

When the input device controls cursor activity on a display, it is called a cursor control device (CCD). CCDs are used to position display cursors on selectable areas of the displays. These selectable areas are "soft controls" intended to perform the same functions as mechanical switches or other controls on conventional control panels.

Typically CCDs provide control of several functions and are the means for directly manipulating display elements. In addition to the above guidelines the following are design considerations unique to CCDs.

(1) The CCD design and installation should enable the flight crew to clearly and precisely control the CCD, and to maintain display configuration control, without exceptional skill during foreseeable flight conditions, both normal and adverse (e.g. turbulence, vibrations). Certain selection techniques, such as double or triple clicks, should be avoided..

(2) The safety assessment of the CCD may need to address reversion to alternate means of control following loss of the CCD. This includes an assessment on the impact of the failure on crew workload.

(3) The functionality of the CCD should be demonstrated with respect to the flight crew interface considerations outlined below:

(a) The ability of the flight crew to share tasks, following CCD failure, with appropriate workload and efficiency.
(b) The ability of the flight crew to use the CCD with accuracy and speed of selection, required of the related tasks, under foreseeable operating conditions (e.g. turbulence, engine imbalance. vibration).
(c) Satisfactory flight crew task performance and CCD functionality, whether the CCD is operated with a dominant or non-dominant hand.
(d) Hand stability support position (e.g. wrist rest).
(e) Ease of recovery from incorrect use.

9.4 Cursor Display

(1) The cursor display should be restricted from areas of primary flight information or where occlusion of display information by a cursor could result in misinterpretation by the crew. If a cursor is allowed to enter a critical display information field, it should be demonstrated to not cause interference for all phases of flight and failure conditions that it will be presented in.

(2) Manipulation of the cursor on the display allows crew access to display elements. Because it is a directly controllable element on the display it has unique characteristics that need consideration:

(a) Presentation of the cursor should be clear, unambiguous, and easily detectable in all foreseeable operating conditions.
(b) The failure mode of an uncontrollable and distracting display of the cursor should be evaluated.
(c) Because in most applications more than one crew member will be using the cursor, the applicant should establish an acceptable method for handling “dueling cursors” that is compatible with the overall flight deck philosophy (e.g., “last person on display wins”).
(d) If a cursor is allowed to fade from a display, some means should be employed for the crew to quickly locate it on the display system. Common examples of this are “blooming” or “growing” the cursor to attract the crew’s attention.
(e) A means should be provided to distinguish between cursors if more than one is used on a display system.

10 Compliance Considerations (Test and Compliance)

This section provides considerations and guidance for demonstrating compliance to the regulations for the approval of electronic flight deck displays. Since some much of display system compliance is dependent on subjective evaluations by pilots and human factors specialist, this section will focus on providing specific guidance that facilitates these types of evaluations.

The acceptable means of compliance (MOC) for a given display system may depend on many factors, and is determined on a case-by-case basis. For example, when the proposed display system is mature and well understood, less rigorous means such as analogical reasoning (i.e., documented as a Statement of Similarity) may be sufficient. However, more rigorous and structured methods (e.g., analysis and flight test) are appropriate if, for example, the proposed display system design is deemed novel, complex or highly integrated.

In selecting the MOC, other factors might include the subjectivity of the acceptance criteria, and the evaluation facilities of the applicant (e.g., high-fidelity flight simulators). Furthermore, the manner in which these facilities are used (e.g., data collection) are influenced by the considerations listed below.

10.1 Means of Compliance (MOC) Descriptions

The following MOC descriptions are focused on electronic displays:

A. System Descriptions. System descriptions may include a system architecture, description of the layout and general arrangement of the flight deck, description of the intended function, crew interfaces, system interfaces, functionality, operational modes, mode transitions, and characteristics (e.g. dynamics of the display system), and applicable requirements addressed by this description. Layout drawings and/or engineering drawings may show the geometric arrangement of hardware or display graphics. Drawings typically are used when demonstration of compliance can easily be reduced to simple geometry, arrangement, or the presence of a given feature, on a technical drawing. The following questions may be used to evaluate whether the description of intended function is sufficiently specific and detailed:

- Does each system, feature and function have a stated intended function?
- What assessments, decisions, or actions are the flight crewmembers intended to make based on the display system?
- What other information is assumed to be used in combination with the display system?
- What is the assumed operational environment in which the equipment will be used (e.g., the pilots tasks and operations within the flight deck, phase of flight and flight procedures)

B. Statement of similarity. This is a substantiation to demonstrate compliance by a comparison to a previously approved display (system or function). The comparison details the physical, logical, and functional and operational similarities of the two systems. This method of compliance should be used with care because the flight deck should be evaluated as a whole, rather than merely as a set of individual functions or systems. For example, display functions that have been previously approved on different programs may be incompatible when applied to another flight deck. Also, changing one feature in a flight deck may necessitate corresponding changes in other features, in order to maintain consistency and prevent confusion.

C. Calculation & Engineering Analysis. These include assumptions of relevant parameters and contexts, such as the operational environment, pilot population, and pilot training. For analyses that are not based on advisory material or accepted industry standards, validation of calculations and engineering analysis using direct participant interaction with the display should be considered. Examples of analysis include computer modeling to show performance (e.g. optical performance) and human performance timing (e.g., latency, potential workload).

D. Evaluation. This is an assessment of the design, conducted by the applicant, who then provides a report of the results to the Authority. Evaluations have two defining characteristics that distinguish themselves from tests: (1) the representation of the display design does not necessarily conform to the final documentation, and (2) the Authority does not need to be present. Evaluations may contribute to a finding of compliance, but they generally do not constitute a finding of compliance by themselves.

   Evaluations may begin early in the program. They may involve static assessments of the basic design and layout of the display, part-task evaluations and/or, full task evaluations in an operationally representative environment (environment may be simulated). A wide variety of development tools may be used for evaluations, from mockups to full installation representations of the actual product or flight deck.

   In cases where human subjects (typically pilots) are used to gather data (subjective or objective), the applicant should fully document the process used to select subjects, the type of data collected, and the method(s) used to collect the data. This should be provided to the Authority in advance to get agreement on the extent to which the evaluations are valid and relevant for certification credit. Additionally, credit will depend on the extent to which the equipment and facilities actually represent the flight deck configuration and realism of the flight crew tasks.

E. Test. This MOC is conducted in a manner very similar to evaluations (see above), but is performed on conformed systems (or conformed items relevant to the test), in accordance with an approved test plan, with either the aircraft certification authority or their designated representative present. A test can be conducted on a test bench, in a simulator, and/or on the actual aircraft, and is often more formal, structured and rigorous than an evaluation.

   Bench or simulator tests that are conducted to show compliance should be performed in an environment that adequately represents the airplane environment, for the purpose of those tests. Flight tests can be the validation and verification of other data, such as display unusual attitude behavior from analysis, evaluations, and simulation. It is often best to use flight tests as a final confirmation of data collected using other means of compliance. "Workload assessments in the presence of failures and validation of failure effect classification need to be addressed in a simulator and/or the actual airplane during certification."

11 Considerations for Continued Airworthiness and Maintenance

This section provides guidance for the preparation of instructions for continued airworthiness of the display system and its components, to show compliance with 25.1309 and 25.1529 (including Appendix H) which requires that Instructions for Continued Airworthiness should be prepared. The guidance given is not a definitive list, and other maintenance tasks may be developed as a result of the safety assessment, design reviews, manufacturer's recommendations, and Maintenance Steering Group (MSG)-3 analyses that are conducted.

11.1 General Considerations

Information on the preparation of the instructions for continued airworthiness can be found in Appendix H to Part 25.

(i) If the display system uses pin programming by software means, maintenance information should be provided to enable replacement display equipment to be programmed with the approved airplane configuration.

(ii) Maintenance procedures may also need to be considered for:

(a)Reversionary switches if they are not used in normal operation. The concern is that they are potential latent failures, and consequently the switching or back up display/sensor may not be available when required. These failures may be addressed by a System Safety Assessment, and in the preparation of the airplane's maintenance program (e.g. MSG-3).

(b) Display cooling fans and filters integral with cooling ducting.

11.2 Design for Maintainability

The system should be designed to minimize maintenance error:

(i)The display mounting, connectors, and labeling, should allow quick, easy, safe, and correct access, for identification, removal and replacement. Means should be provided (e.g. physically coded connectors) to prevent inappropriate connections of system elements

(ii) If the system has the capability of providing information on system faults (e.g. diagnostics) to maintenance personnel, it should be displayed in text instead of coded information.

(iii) If the flight crew needs to provide information to the maintenance personnel (example: Overheat warning), problems associated with the display system should be communicated to the flight crew as appropriate, relative to the task and criticality of the information displayed.

(iv) Suitable maintenance instructions should be provided with installation design changes. For example, this may include wiring diagram information addressing pin programming, following the incorporation of a Supplemental Type Certificate (STC) that introduces a new or modified interface to the display system.

11.3 Maintenance of Display Characteristics

Maintenance procedures may be used to ensure that the display characteristics remain within the levels presented and accepted at certification.

Experience has shown that display quality may degrade with time and become difficult to use. Examples are: lower brightness/contrast; distortion or discoloration of the screen (blooming effects); and parts of the screens that may not display information properly.

Test methods and criteria may be established to determine if the display system remains within acceptable minimum levels. Display system manufacturers may alternatively provide “end of life“ specifications for the displays which could be adopted by the aircraft manufacturer.

12 Glossary of Acronyms/Abbreviations

AC – Advisory Circular
ADI- Attitude Director Indicator
AFM-Airplane Flight Manual
AMC-Acceptable Means of Compliance
AMJ - Advisory Material Joint
ARP-Aerospace Recommended Practices
AS-Aerospace Standard
CAS- Crew Alerting System
CCD- Curser Control Device
CDI- Course Deviation Indicator
CFIT - controlled flight into terrain
CFR – Code of Federal Regulations
CIE- Commissions Internationale de L'Eclairage
COM-Communication
CRT – Cathode Ray Tube
CS-Certification Specification (EASA Only)
DAL - Development Assurance Level
DEP- Design Eye Position
DME-Distance Measuring Equipment
DOD-Department of Defense
DU- Display Unit
EADI-Electronic Attitude Direction Indicator
EASA- European Aviation Safety Agency
EDS - Electronic Display System
EFB – Electronic Flight Bag
EGT- Exhaust Gas Temperature
EHSI-Electronic Horizontal Situation Indicator
EICAS –Engine Indicating and Crew Alerting System
ETSO-European Technical Standard Order
EURCAE – European Organization for Civil Aviation Equipment
EVS-Enhanced Vision System
FAA – Federal Aviation Administration
FADEC - Full Authority Digital Engine Controls
FHA- Functional Hazard Assessment
FMS-Flight Management System
FOV-Field of View
GLS – GNSS (Global Navigation Satellite System) Landing System
GPS – Global Positioning System
GUI-Graphical User Interface
HDD- Head down Display
HUD –Head up Display
ICAO-International Civil Aviation Organization
IFE - In Flight Entertainment
ILS-Instrument Landing System
INS- Inertial Navigation System
I/O- Input/Output
ISD-Integrated Standby Display
JAA- Joint Airworthiness Authority
LCD –Liquid Crystal Display
LED-Light Emitting Diode
MASPS- Minimum Aviation System Performance Standard

MFD- Mutli-Function Display
MIL STD- Military Standard
MMO- Maximum Operating Mach Number
MOC - Means Of Compliance
MOPS- Minimum Operational Performance Standard
MSG - Maintenance Steering Group
ND-Navigation Display
PFD-Primary Flight Display
PFI-Primary Flight Information
PI-Powerplant Information
SA-Situation Awareness
SAE- Society of Automotive Engineers
STC - Supplemental Type Certificate
SVS-Synthetic Vision System
TAWS-Terrain Awareness and Warning System
TCAS-Traffic Alert and Collision Avoidance System
TSO-Technical Standard Order
UA - User Application
VHF-Very High Frequency
VMO- Maximum Operation Speed
VOR- Very High Frequency Omnirange

13 Definitions

Basic T – The arrangement of primary flight information as required by 25.1321(b); including attitude, airspeed, altitude, and direction information.

Brightness: The perceived or subjective luminance. As such, it should not be confused with **luminance**.

Chrominance – The quality of a display image which includes both luminance and chromaticity and is a perceptual construct subjectively assessed by the human observer.

Chromaticity: Color characteristic of a symbol or an image defined by its u', v' coordinates (CIE pub number 15.2, Colorimetry, second edition 1986).

Coding characteristics: Coding characteristics are readily identifiable attributes commonly associated with a symbol by means of which such symbols are differentiated; i.e., size, shape, color, motion, location, etc.

Color coding – A means to use color to differentiate display information.

Command information: Displayed information directing a control action.

Compact mode – In display use, this most frequently refers to a single, condensed display presented in numeric format that is used during reversionary or failure conditions.

Conformal: Refers to displayed information which overlays the real world element that it is meant to portray irrespective of the viewing position.

Contrast Ratio:
For HUD – ratio of the luminance over the background scene (AS 8055)
For HDD – ratio of the total foreground luminance to the total background luminance

Criticality: Indication of the hazard level associated with a function, hardware, software, etc., considering abnormal behavior (of this function, hardware, software) alone, in combination, or in combination with external events.

Design eye position: The position at each pilot's station from which a seated pilot achieves the optimum combination of outside visibility and instrument scan. The design eye position is a single point selected by the applicant that meets the requirements of Secs. 25.773(d) and 25.777(c) for each pilot station. It is normally a point fixed in relation to the aircraft structure (neutral seat reference point) at which the midpoint of the pilot's eyes should be located when seated at the normal position. The DEP is the principal dimensional reference point for the location of flight deck panels, controls, displays, and external vision.

Display refresh rate: The rate at which a display completely refreshes its image

Display response time: time needed to change the information from one level of luminance to a different level of luminance. Display response time related to the **intrinsic response** (time linked to the electro-optic effect used for the display and the way to address it).

Display Surface/Screen: The area of the display unit that provides an image.

Display System: The entire set of avionic devices implemented to display information to the flight crew. Also known as an Electronic Display System (EDS)

Display Unit: A line replaceable unit that is located in the flight deck, in direct view of the flight crew, that is used to provide display information. Examples include a color head down display, and a head up display projector and combiner.

Enhanced Vision System (EVS): An electronic means to provide a display of the forward external scene topography (natural or manmade features of a place or region especially in a way to show their relative positions and elevation) through the use of imaging sensors, such as a forward looking infrared, millimeter wave radiometry, millimeter wave radar, low light level image intensifying. Note: An Enhanced Flight Vision System (EFVS) is an EVS that is intended to be used for instrument approaches under provisions of 14 CFR §91.175 (l) and (m), and must display the imagery with instrument flight information on a head up display.

Eye Reference Position: A single spatial position located at or near the center of the HUD Eye Box. The HUD ERP is the primary geometrical reference point for the HUD.

Failure: An occurrence which affects the operation of a component, part, or element, such that it can no longer function as intended (this includes both loss of function and malfunction). Note: errors may cause failures but are not considered to be failures.

Failure Condition: A condition having an effect on the airplane and/or its occupants, either direct or consequential, which is caused or contributed to by one or more failures or errors, considering flight phase and relevant adverse operational or environmental conditions, or external events.

Field of View: The angular extent of the display that can be seen by either pilot with the pilot seated at the pilot's station.

Flicker – An undesirable display effect that occurs when a display does not generate quickly enough and can cause discomfort for the viewer (such as headaches and irritation).

Flight Deck Philosophy – A high level description of the design principles that guide the designer and ensure a consistent and coherent interface is presented to the flight crew.

Functional Hazard Assessment: A systematic, comprehensive examination of airplane and system function to identify potential Minor, Major, Hazardous, and Catastrophic failure conditions that may arise as a result of a malfunction or a failure to function.

Format (Fig 13-2): An image rendered on the whole display unit surface. A format is constructed from one or more windows (Ref ARINC661)

Gray Scale: number of incremental luminance levels between full dark and full bright

Hazard: Any condition that compromises the overall safety of the airplane or that significantly reduces the ability of the flight crew to cope with adverse operating conditions.

HUD Design eye box: The three-dimensional area surrounding the design eye position, which defines the area, from which the HUD symbology performance parameters are defined.

Icon – A single graphical symbol that represents a function or event.

Image Size: useful viewing area (field) of the display surface.
- Direct view display: it refers to the useful (or active) area of the display (ex: units cm x cm)
- Head Up Display: the Total Field Of View (units usually in degrees x degrees)

(Total field of view defines the maximum angular extent of the display that can be seen by either eye allowing head motion within the eyebox. (AS8055))

Indication: Any visual information - e.g. graphical gauges, graphical representations, numeric data displays (i.e. numeric), messages, lights, symbols, synoptics, etc.

Information update rate: The rate at which new data is displayed or updated**.**

Interaction – the ability to directly affect a display by utilizing a graphical user interface (GUI) that consists of a control device (e.g, trackball), cursor, and "soft" display control that is the cursor target.

Latency: The time taken by the display system to react to a triggered event coming from I/O device, the symbol generator, the graphic processor, or the information source).

Layer (Fig 13-3): A layer is the highest level entity of the Display System that is known by a User Application (UA).

Luminance: Visible light that is emitted from the display. Commonly-used units: foot-lamberts, cd/m^2

Menu: A displayed list of items from which the flight crewmember can choose

Mirror image – the arrangement of a pair of displays or control panels where the images or controls are laid out such that they are flipped representations of each other.

Misleading Information: Misleading information is incorrect information that is not detected by the flight crew because it appears as correct and credible information under the given circumstances.

When incorrect information is automatically detected by a monitor resulting in an indication to the flight crew or when the information is obviously incorrect, it is no longer considered misleading.

The consequence of misleading information will depend on the nature of the information, and the given circumstances.

Mode: A mode is the functional state of a display and/or control system(s). A mode can be manually or automatically selected.

Occlusion: Visual blocking of one symbol by another. Sometimes called sparing or occulting.

Partitioning – A technique for providing isolation between functionality independent software components to contain and/or isolate faults and potentially reduce the effort of the software verification process.

Pixel: LCD picture element which usually consists of three (red, green, blue) sub-pixels (also called dots on a CRT).

Primary Displays – The display used to present primary flight information.

Primary Field of View (FOV) – Primary Field-of-View is based upon the optimum vertical and horizontal visual fields from the design eye reference point that can be accommodated with eye rotation only.   The description below provides an example of how this may apply to head-down displays.

Primary flight information – The information whose presentation is required by 25.1303(b) and 25.1333(b), and arranged by 25.1321(b).

Primary flight instrument - A primary flight instrument is any display or instrument that serves as the flight crew's primary reference of a specific parameter of primary flight information. For example, a centrally located attitude director indicator (ADI) is a primary flight instrument because it is the flight crew's primary reference for pitch, bank, and command steering information.

Primary flight reference (PFR): A primary flight reference is any display, or suite of displays or instruments, that provides the flight crew with primary flight information.

Resolution: Size of the minimum element that can be displayed, expressed by the total number of pixels or dots.

Pixel Defect: A pixel that appears to be in a permanently on or off-state.

Required Powerplant Parameters – The information whose presentation is required by 25.1305.

Reversionary – This event occurs refers to the crew initiated (manual) or automatic relocation of displays following a display failure.

Shading - Shading is a variation on chromatic coordinates along an axis. Shading is used as:
- a coding method for separating information, change in state, give emphasis, and depth information
- a blending method between graphic elements (map displays, SVS)
- to enhance similarity between a synthetic image and the real world image

Software control – display elements used to manipulate, select, or de-select information (e.g. menus and soft keys)

Standby Display – A backup display that is used in case of a primary display malfunction.

Status information: Information about the current condition of an airplane system and its surroundings.

Symbol: A symbol is a geometric form or alphanumeric information used to represent the state of a parameter on a display. The symbol maybe further defined by its location and motion on a display.

Synthetic Vision System: A system which creates computer generated imagery or symbology representing how an outside forward vision scene would otherwise appear, or elements of that scene would appear, if a pilot could optically see through the visibility restriction or darkness.

Texturing - Texturing is a graphic, pictorial effect placed on a display surface to give the surface a specific "look" (metallic, grassy, cloudy, etc.). Texturing is used as:
- a coding method for separating information, change in state, give emphasis, and depth information
- a blending method between graphic elements (map displays, SVS)
- to enhance similarity between a synthetic image and the real world image

Transparency – Transparency is a way of allowing seeing "through" a front element what's "behind". By doing this, it can alter the color perception of both the "front" and "back" element.

User Application: A user application is an avionics system, interfaced with the display system, which uses the display system as a resource to display and collect information related to its own function (Ref. A661).

User Application Layer Definition or Definition file: The layer definition or definition file is a software file, running on the display system but defined by the user application which describes the constitution of images (widgets hierarchical structure) as needed by the User Application (Ref. ARINC661).

Viewing Envelope (Fig 13-1): total volume of space where the minimum optical performance of the display is met (e.g. luminance, contrast, chromaticity.). For a direct view display it is the solid angle with respect to the normal of the display image and for a HUD a three- dimensional volume (Eyebox).

Widget (Fig 13-3): A single graphical object. A widget is a generic object whose parameters can be set dynamically by a User Application.

Window (Fig 13-2, 13-3): A rectangular physical area of the display surface. A window consists of one or more layers (Ref. ARINC661).

Windowing – The technique to create windows. Segmenting a single display area into two or more independent display areas or inserting a new display area onto an existing display.

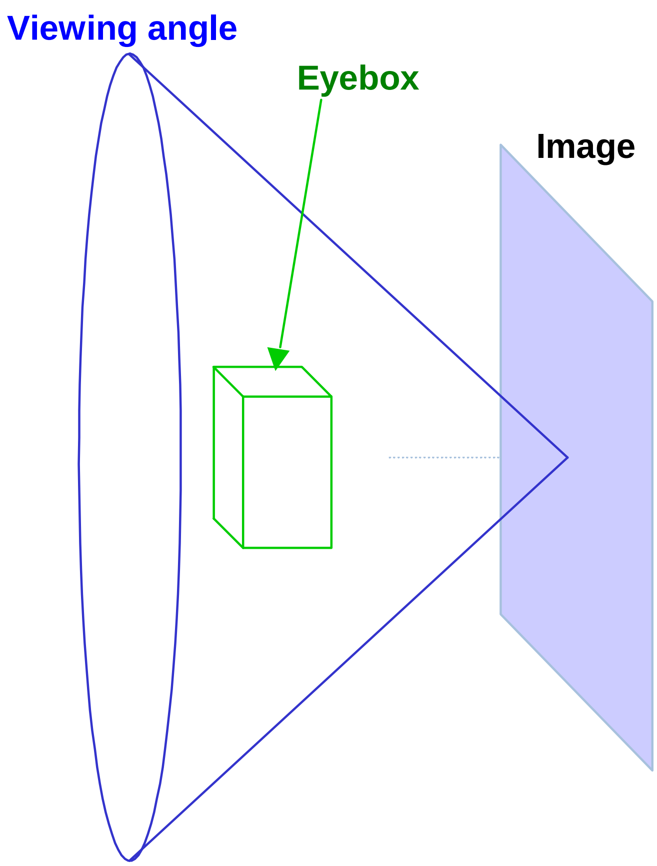


Figure 13-1 – Viewing Envelope

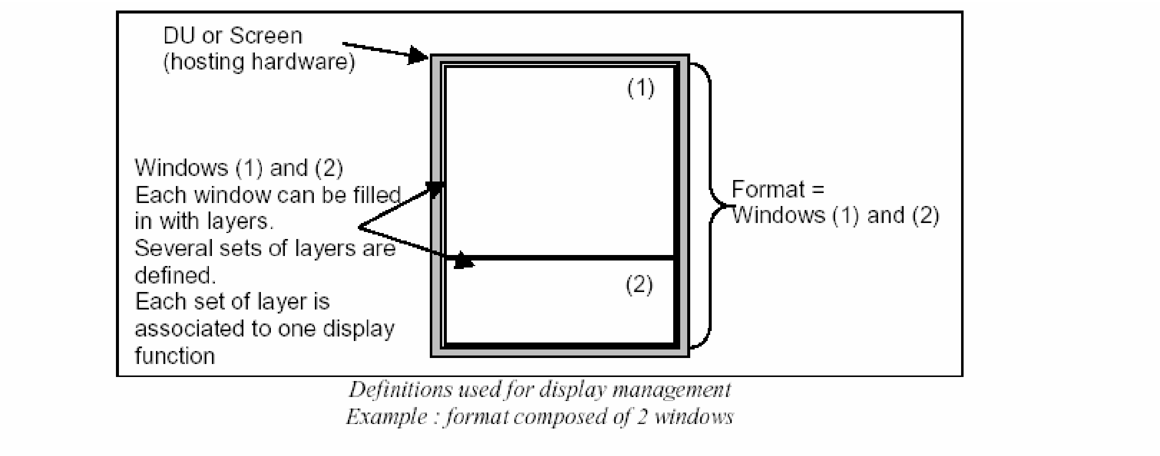


Figure 13-2 – Display Format

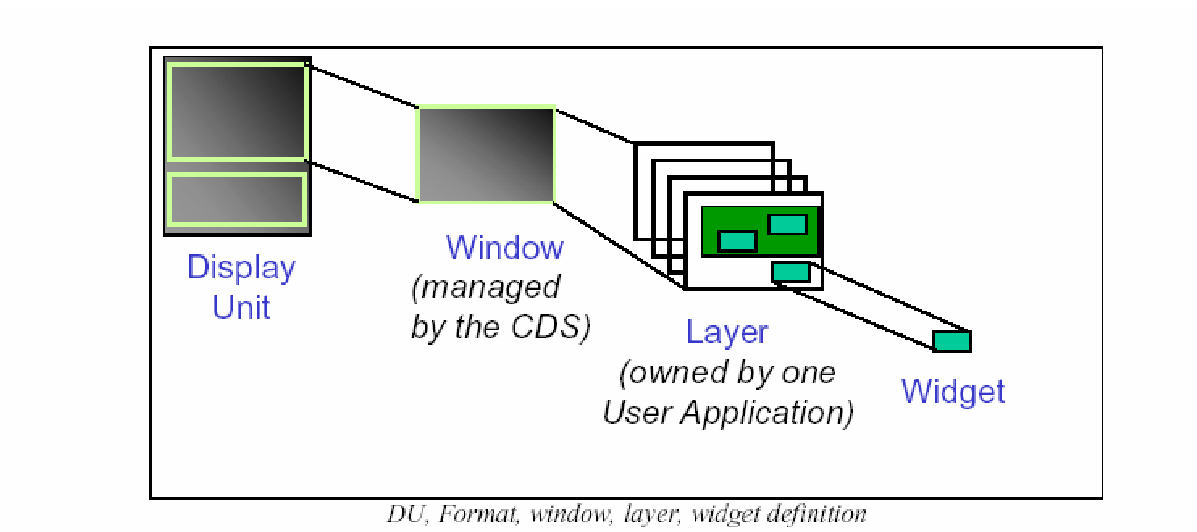


Figure 13-3 – Display Window, Layer, Wigdet relationship

.

14 Related Regulations and Documents

14.1 General

The regulations and standards listed below are applicable to particular systems or functions which may have implications on the display system characteristics even though they do not explicitly state display requirements. It is not an exhaustive list, and the references should be reviewed to ensure currency of issue status, and to check for any others that may be applicable.

14.2 Regulatory Sections

The following is a complete list of regulations/certifications that should be considered when certifying a display system:

§ 25.143 Controllability and Maneuverability: General
§ 25.207 Stall warning
§ 25.672 Stability augmentation and power operated systems
§ 25.677 Trim systems
§ 25.679 Control system gust locks
§ 25.699 Lift and drag device indicator
§ 25.703 Takeoff warning system
§ 25.729 Retracting mechanism
§ 25.771 Pilot compartment
§ 25.773 Pilot compartment view
§ 25.777 Cockpit controls
§ 25.783 Doors
§ 25.812 Emergency lighting
§ 25.841 Pressurized cabins
§ 25.854 Lavatory fire protection
§ 25.857 Cargo compartment classification
§ 25.858 Cargo or baggage compartment smoke or fire detection systems
§ 25.859 Combustion heater fire protection
§ 25.863 Flammable fluid fire protection
§ 25.901 Powerplant installation
§ 25.903 Engines
§ 25.904 Automatic takeoff thrust control system (ATTCS)
§ 25.1001 Fuel Jettison Systems
§ 25.1019 Oil strainer or filter
§ 25.1141 Powerplant controls: General
§ 25.1165 Engine ignition systems
§ 25.1199 Extinguishing agent containers
§ 25.1203 Fire detector system
§ 25.1301 Function and installation
§ 25.1303 Flight and navigation instruments
§ 25.1305 Powerplant instruments
§ 25.1309 Equipment, systems, and installations
§ 25.1316 System lightning protection
§ 25.1321 Arrangement and visibility
§ 25.1322 Warning, caution, and advisory lights
§ 25.1323 Airspeed indicating system

§ 25.1326 Pitot heat indication systems
§ 25.1327 Magnetic direction indicator
§ 25.1329 Automatic pilot system
§ 25.1331 Instruments using a power supply
§ 25.1333 Instrument systems
§ 25.1335 Flight director systems
§ 25.1337 Powerplant instruments
§ 25.1351 Electrical Systems and Equipment: General
§ 25.1353 Electrical equipment and installations
§ 25.1355 Distribution system
§ 25.1357 Circuit protective devices
§ 25.1381 Instrument lights
§ 25.1383 Landing lights
§ 25.1419 Ice protection
§ 25.1431 Electronic equipment
§ 25.1435 Hydraulic systems
§ 25.1441 Oxygen equipment and supply
§ 25.1457 Cockpit voice recorders
§ 25.1459 Flight recorders
§ 25.1501 Operating Limitations and Information: General
§ 25.1523 Minimum flight crew
§ 25.1529 Instructions for Continued Airworthiness
§ 25.1541 Markings and Placards: General
§ 25.1543 Instrument markings: General
§ 25.1545 Airspeed limitation information
§ 25.1547 Magnetic direction indicator
§ 25.1549 Powerplant and auxiliary power unit instruments
§ 25.1551 Oil quantity indication
§ 25.1553 Fuel quantity indicator
§ 25.1555 Control markings
§ 25.1563 Airspeed placard
§ 25.1581 Airplane Flight Manual :General
§ 25.1583 Operating limitations
§ 25.1585 Operating procedures
§ 33.71 Lubrication System
§ 91.33 Instrument and equipment requirements
§ 91.205 Powered civil aircraft with standard category U.S. airworthiness certificates: Instrument and equipment requirements
§ 91.219 Altitude alerting system or device; turbojet powered civil airplanes
§ 91.221 Traffic Alert and Collision Avoidance System Equipment and use
§ 91.223 Terrain Awareness and Warning System
CFR 91 Appendix A, Section 2 Required Instruments and Equipment
§ 121.221 Fire Precautions
§ 121.305 Flight and navigational equipment
§ 121.307 Engine Instruments
§ 121.308 Lavatory Fire Protection
§ 121.313 Miscellaneous Equipment
§ 121.323 Instruments and Equipment for Operations at Night
§ 121.325 Instruments and Equipment for Operations under IFR or Over-the-Top
§ 121.344 Digital Flight Data Recorders for Transport Category Aeroplanes (note : DFDRs may be required to record Electronic display status)
§ 121.354 Terrain awareness and warning system
§ 121.356 Traffic Alert and Collision Avoidance System
§ 121.357 Airborne Weather Radar Equipment Requirements
§ 121.358 Low-Altitude Windshear Systems Requirements

§ 121.360 Ground proximity warning – glideslope deviation alerting system
§ 135.149 Equipment requirements: General
§ 135.153 Ground Proximity Warning System
§ 135.154 Terrain Awareness and Warning System
§ 135.159 Equipment requirements: Carrying passengers under Visual Flight Rules (VFR) at night or under VFR over-the-top conditions
§ 135.163 Equipment requirements: Aircraft carrying passengers under Instrument Flight Rules (IFR)
§ 135.180 Traffic Alert and Collision Alerting System
CFR 135 Appendix A, Additional Airworthiness Standards for Ten or More Passenger Airplanes

14.3 Advisory Circulars and Related Documents

(1) FAA Documents

Note: The ACs, Orders and policy memorandum can be accessed on the FAA website: www.faa.gov. Copies of current editions of the following publications may be obtained free of charge from the U.S. Department of Transportation, Subsequent Distribution Office, M-30, Ardmore East Business Center, 3341 Q 75th Avenue, Landover, MD 20785.

AC20-88A	Guidelines on the Marking of Aircraft Powerplant Instruments (Displays)
AC 20-115B	Radio Technical Commission for Aeronautic, Inc. Document RTCA/DO-178B
AC20-129	Airworthiness Approval of Vertical Navigation (VNAV) Systems for use in the National Airspace System (NAS) and Alaska
AC20-130A	Airworthiness approval of Navigation or Flight Management Systems Integrating Multiple Navigation Sensors
AC20-131A	Airworthiness approval of Traffic Alert and Collision Avoidance Systems (TCAS II) and mode S transponders
AC 20-136	Protection of Aircraft Electrical/Electronic Systems against the Indirect Effects of Lightning
AC20-138A	Airworthiness approval of Global Navigation Satellite Systems (GNSS) Equipment
AC20-140	Guideline for Design Approval of Aircraft Data Communications Systems
AC 20-145	Guidance For Integrated Modular Avionics (IMA) that Implement TSO-C153 Authorized Hardware Elements
AC20-151	Airworthiness Approval of Traffic Alert and Collision Avoidance Systems (TCAS II) Version 7.0 and Associated Mode S Transponders
AC20-152	RTCA, Inc., Document RTCA/DO-254, Design Assurance Guidance for Airborne Electronic Hardware
AC20-155	SAE Documents to Support Aircraft Lightning Protection Certification

AC 25-4	Inertial Navigation System (INS)
AC 25-7A	Flight Test Guide for Certification of Transport Category Airplanes
AC 25-12	Airworthiness Criteria for the Approval of Airborne Windshear Warning Systems in Transport Category
AC25-15	Approval of Flight Management Systems in Transport Category Airplanes
AC 25-23	Airworthiness Criteria for the Installation Approval of aTerrain Awareness and Warning System (TAWS) for Part 25 Airplanes
AC 25-24	Sustained Engine Imbalance
AC 25-703-1	Takeoff Configuration warning Systems
AC 25.1309-1A	System Design and Analysis
AC25.1329-1A	Automatic Pilot Systems Approval
AC 90-45A	Approval of Area Navigation Systems for use in the US National Airspace System
AC120-28D	Criteria for Approval of Category III Weather Minima for Takeoff, Landing, and Rollout
AC120-29A	Criteria for Approval of Category I and Category II Weather Minima for Approach.
AC120-41	Criteria for Operational Approval of Airborne Wind Shear Alerting and Flight Guidance
AC120-55B	Air Carrier Operational Approval and Use of TCAS II
AC120-64	Operational Use and Modification of Electronic Checklists
AC 120-76A	Guidelines for the Certification, Airworthiness, and Operational Approval of Electronic Flight Bag Computing Devices
Order 8110.49	Software Approval Guidelines, dated June 3, 2003
PS-ACE100-2001-004	Guidance for Reviewing Certification Plans to Address Human Factors for Certification of Part 25 Small Airplanes
DOT/FAA/CT-03/05	Human Factors Design Standards for Acquisition of Commercial Off-The-Shelf Subsystems, Non-Developmental Items, and Developmental Systems. This document can be accessed on the FAA website: www.hf.faa.gov.
DOT/FAA/OAM-TM-03-01	Multi-Function Displays A Guide for Human Factors Evaluations
ICAO 8400/5	Procedures for Air Navigation Services, ICAO Abbreviations and Codes. Fifth Edition-1999.

(2) JAA/EASA Documents

Note: Copies of the EASA documents can be obtained from the EASA website www.EASA.eu.int/agency measures. JAA documents have to be purchased separately.

AMC 20-4	Airworthiness Approval and Operational Criteria for the use of Navigation Systems in European Airspace Designated for Basic RNAV Operations.
AMC 20-5	Airworthiness Approval and Operational Criteria for the use of the Navstar Global Positioning System (GPS).
JAA TGL 8, Revision 2	Certification Considerations for the Airborne Collision Avoidance System : ACAS II.
JAA TGL 10, Rev. 1	Airworthiness and operational approval for precision RNAV operations in designated European airspace
JAA TGL 12	Certification Considerations for the Terrain Awareness and Warning System :TAWS.
CS AWO	All Weather Operations

(3) Technical Standard Orders (TSO)

Note : You may obtain a copy of the current edition of the following publications from the Federal Aviation Administration; Aircraft Certification Service; Aircraft Engineering Division; Technical and Administrative Support Staff Branch, AIR-103; 800 Independence Avenue, SW; Washington, DC 20591 or at the FAA website: www.faa.gov. The following is a partial list of the FAA Technical Standard Orders (TSOs) that may relate to electronic displays. For a complete list of TSOs, see AC 20-110, "Index of Aviation Technical Standards Orders." It should be noted applicants might apply for a TSO that does not adequately address all of the functionality in the system. Alternatively, applicants may apply for multiple TSOs, since no single TSO applies to all functions.

PARTIAL INDEX OF TSOs THAT MAY BE APPLICABLE

TSO-C2d	Airspeed Instruments
TSO-C3d	Turn and Slip Instrument
TSO-C4c	Bank and Pitch Instruments
TSO-C5e	Direction Instrument, Non-magnetic (Gyroscopically Stabilized)
TSO-C6d	Direction Instrument, Magnetic (Gyroscopically Stabilized)
TSO-C7d	Direction Instrument, Magnetic Non-Stabilized Type (Magnetic Compass)
TSO-C8d	Vertical Velocity Instruments (Rate-of-Climb)
TSO-C9c	Automatic Pilots
TSO-C10b	Altimeter, Pressure Actuated, Sensitive Type

TSO-C31d	High Frequency (HF) Radio Communications Transmitting Equipment Operating within the Radio Frequency Range of 1.5-30 Megahertz
TSO-C34e	ILS Glide Slope Receiving Equipment Operating within the Radio Frequency Range of 328.6-335.4 Megahertz (MHz)
TSO-C35d	Airborne Radio Marker Receiving Equipment
TSO-C36e	Airborne ILS Localizer Receiving Equipment Operating within the Radio Frequency Range of 108-112 Megahertz (MHz)
TSO-C37d	VHF Radio Communications Transmitting Equipment Operating within the Radio Frequency Range 117.975 to 137.000 Megahertz
TSO-C38d	VHF Radio Communications Receiving Equipment Operating within the Radio Frequency Range 117.975 to 137.000 Megahertz
TSO-C40c	VOR Receiving Equipment Operating within the Radio Frequency Range of 108-117.95 Megahertz (MHz)
TSO-C41d	Airborne Automatic Direction Finding (ADF) Equipment
TSO-C43c	Temperature Instruments
TSO-C44b	Fuel Flowmeters
TSO-C46a	Maximum Allowable Airspeed Indicator Systems
TSO-C47	Pressure Instruments – Fuel, Oil, and Hydraulic
TSO-C49b	Electric Tachometer: Magnetic Drag (Indicator and Generator).
TSO-C52b	Flight Director Equipment
TSO-C54	Stall Warning Instruments
TSO-C55	Fuel and Oil Quantity Instruments (Reciprocating Engine Aircraft)
TSO-C63c	Airborne Weather and Ground Mapping Pulsed Radars
TSO-C66c	Distance Measuring Equipment (DME) Operating within the Radio Frequency Range of 960-1215 Megahertz
TSO-C67	Airborne Radar Altimeter Equipment (For Air Carrier Aircraft)
TSO-C87	Airborne Low-Range Radio Altimeter
TSO-C92c	Airborne Ground Proximity Warning Equipment

TSO-C93	Airborne Interim Standard Microwave Landing System Converter Equipment
TSO-C94a	Omega Receiving Equipment Operating within the Radio Frequency Range of 10.2 to 13.6 Kilohertz
TSO-C95	Mach Meters
TSO-C101	Over Speed Warning Instruments
TSO-C104	Microwave Landing System (MLS) Airborne Receiving Equipment
TSO-C105	Optional Display Equipment for Weather and Ground Mapping Radar Indicators
TSO-C106	Air Data Computer
TSO-C110a	Airborne Passive Thunderstorm Detection Equipment
TSO-C113	Airborne Multipurpose Electronic Displays
TSO-C115b	Airborne Area Navigation Equipment Using Multi-Sensor Inputs
TSO-C117a	Airborne Windshear Warning and Escape Guidance Systems for Transport Airplanes
TSO-C118	Traffic Alert and Collision Avoidance System (TCAS) Airborne Equipment, TCAS I
TSO-C119b	Traffic Alert and Collision Avoidance System (TCAS) Airborne Equipment, TCAS II
TSO-C120	Airborne Area Navigation Equipment Using Omega/Very Low Frequency (VLF) Inputs
TSO-C129a	Airborne Supplemental Navigation Equipment Using Global Positioning System (GPS)
TSO-C145a	Airborne Navigation Sensors using the Global Positioning System (GPS) Augmented by the Wide Area Augmentation System (WAAS)
TSO-C146a	Stand-Alone Airborne Navigation Equipment Using the Global Positioning System (GPS) Augmented By the Wide Area Augmentation System (WAAS)
TSO-C147	Traffic Advisory System (TAS) Airborne Equipment
TSO-C151b	Terrain Awareness and Warning System
TSO-C153	Integrated Modular Avionics Hardware Elements

TSO-C165	Electronic Map Display Equipment for Graphical Depiction of Aircraft Position

14.4 Industry Documents

Copies of current editions of the following publications may be obtained as follows and may be suitable resource material for additional information, guidance, and standards for electronic flight deck display systems.

(1) ICAO Documents

International Civil Aviation Organization 8400/5. Procedures for Air Navigation Services ICAO Abbreviations and Codes. Fifth Edition- 1999.6.3.4.1

(2) RTCA Documents

Note: The RTCA documents are available from RTCA, Inc., Suite 805, 1828 L Street NW, Washington, DC 20036-4001 or at their website at www.rtca.org. The list of RTCA documents does not include those MOPS documents referenced in the aforementioned TSOs.

DO-160( )	Environmental Conditions and Test Procedures for Airborne Equipment
DO-178( )	Software Considerations in Airborne Systems and Equipment Certification
DO-236( )	Minimum Aviation System Performance Standards: Required Navigation Performance for Area Navigation
DO-239	Minimum Operational Performance Standards for Traffic Information Service (TIS) Data Link Communications
DO-243	Guidance for Initial Implementation of Cockpit Display of Traffic Information
DO-253A	Minimum Operational Performance Standards for GPS Local Area Augmentation System Airborne Equipment
DO-254	Design Assurance Guidance for Airborne Electronic Hardware
DO-255	Requirements Specification for Avionics Computer Resource (ACR)
DO-257A	Minimum Operational Performance Standards for the Depiction of Navigation Information on Electronic Maps
DO-259	Applications Descriptions for Initial Cockpit Display of Traffic Information (CDTI) Applications
DO-268	Concept of Operations, Night Vision Imaging System for Civil Operators
DO-275	Minimum Operational Performance Standards for Integrated Night Vision Imaging System Equipment

DO-282A	Minimum Operational Performance Standards (MOPS) for Universal Access Tranceiver (UAT) Automatic Dependent Surveillance - Broadcast
DO-283A	Minimum Operational Performance Standards for Required Navigation Performance for Area Navigation
D0-286	Minimum Aviation System Performance Standards (MASPS) for Traffic Information Service – Broadcast (TIS-B).
DO-289	Minimum Aviation System Performance Standards (MASPS) for Aircraft Surveillance Applications.
D0-296	Safety Requirements for Aeronautical Operational Control (AOC) Datalink Messages.

(3) EUROCAE documents

Note: The EUROCAE documents are available from EUROCAE, 102 rue Etienne Dolet 92240, Malakoff, France or at their website at *www.eurocae.org.* The list of EUROCAE documents does not include those MOPS documents referenced in the aforementioned ETSO's.

ED-12( )	Software Considerations in Airborne Systems and Equipment Certification
ED-14( )	Environmental Conditions and Test Procedures for Airborne Equipment
ED-55	MOPS for Flight Data Recorder Systems
ED-75( )	MASPS Required Navigation Performance for Area Navigation
ED-79	Certification Considerations for Highly Integrated or Complex Aircraft Systems
ED-80	Design Assurance Guidance for Airborne Electronic Hardware
ED-81	Certification of Aircraft Electrical/Electronic Systems for the Indirect Effects of Lightning
ED-84	Aircraft Lightning Environment and Related Test Waveform Standard
ED-90A	Radio Frequency Susceptibility Test procedures
ED-91	Aircraft Lightning Zoning Standard
ED-96	Requirements Specification for an Avionics Computer Resource (See Kirk)
ED-98	User Requirements for Terrain and Obstacle Data
ED-107	Guide for Certification of Aircraft in a High Intensity Radiated Field (HIRF) Environment
ED-112	MOPS for Crash Protected Airborne Recorder Systems

(4) Society of Automotive Engineers

Note: The Society of Automotive Engineers (SAE International) documents are available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001 or from their website at www.sae.org.

AS 425C Nomenclature and Abbreviations, Flight Deck Area

ARP426A Compass System Installations

AS 439A Stall Warning Instrument (Turbine Powered Subsonic Aircraft)

ARP 571C Flight Deck Controls and Displays for Communication and Navigation Equipment for Transport Aircraft

AIR818D Aircraft Instrument and Instrument System Standards: Wording, Terminology, Phraseology, and Environmental and Design Standards For

ARP 926B Fault/Failure Analysis Procedure

AIR 1093A Numeral, Letter and Symbol Dimensions for Aircraft Instrument Displays

ARP 1161A Crew Station Lighting—Commercial Aircraft

ARP 1782A Photometric and Colorimetric Measurement Procedures for Airborne Direct View CRT Displays

ARP 1834A Fault/Failure Analysis for Digital Systems and Equipment

ARP 1874 Design Objectives for CRT Displays for Part 25 (Transport) Aircraft

ARP 4032A Human Engineering Considerations in the Application of Color to Electronic Aircraft Displays

ARP 4033 Pilot System Integration

ARP 4101 Flight Deck Layout and Facilities

ARP 4102 Flight Deck Panels, Controls, and Displays

ARP 4102/7 Electronic Displays

ARP4102/8 Flight Deck Head-Up Displays

ARP4102/15 Electronic Data Management System (EDMS)

ARP 4103 Flight Deck Lighting for Commercial Transport Aircraft

ARP 4105B Abbreviations and Acronyms for Use on the Flight Deck

ARP 4256A Design Objectives for Liquid Crystal Displays for Part 25 (Transport) Aircraft

ARP 4260 Photometric and Colorimetric Measurement Procedures for Airborne Flat Panel Displays

ARP 4754 Certification Considerations for Highly Integrated or Complex Aircraft Systems

ARP 4761 Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment

ARP 5287 Optical Measurement Procedures for Airborne Head-Up Display (HUD)

ARP 5288 Transport Category Airplane Head Up Display (HUD) Systems

ARP 5289 Electronic Aeronautical Symbols

ARP 5364 Human Factor Considerations in the Design of Multifunction Display Systems for Civil Aircraft

ARP 5365 Human Interface Criteria for Cockpit Display of Traffic Information

ARP5413 Certification of Aircraft Electrical/Electronic Systems for the Indirect Effects of Lightning

ARP5414 Aircraft Lightning Zoning

ARP5415A Users Manual for Certification of Aircraft Electrical/Electronic Systems for the Indirect Effects of Lighting

AS 8034 Minimum Performance Standard for Airborne Multipurpose Electronic Displays

AS 8055 Minimum Performance Standard for Airborne Head Up Display (HUD)

ARD 50017 Aeronautical Charting (NOTE: Unable to locate in SAE database)

ARD 50062 Human Factors Issues Associated With Terrain Separation Assurance Display Technology (NOTE: Unable to locate in SAE database)

NOTE: In the event of conflicting information, this AC takes precedence as guidance for certification of transport category airplane installations.

(5) ARINC Documents

ARINC 661 – Cockpit Display System Interfaces to User Systems

(6) Other Documents

Commissions Internationale de L'Eclairage (CIE) pub number 15.2, Colorimetry, second edition 1986).

Appendix A: Primary Flight Information (PFI)

This section provides additional guidance on the display of primary flight information elements, which is the information whose presentation is required by 25.1303(b), 1333(b) and arranged by 1321(b).

A.1 Attitude

Pitch attitude display scaling should be such that during normal maneuvers (such as takeoff at high thrust-to-weight ratios) the horizon remains visible in the display with at least 5 degrees pitch margin available.

An accurate, easy, quick-glance interpretation of attitude should be possible for all unusual attitude situations. Information to perform effective manual recovery from unusual attitudes using chevrons, sky pointers, and/or permanent ground-sky horizon on all attitude indications is recommended.

Both fixed airplane reference and fixed earth reference bank pointers ("sky" pointers) have been found to be acceptable as a reference point for primary attitude information. A mix of these types in the same flight deck is not recommended.

There should be a means to determine the margin to stall and display it when necessary. For example, a pitch limit indication has been found to be acceptable.

There should be a means to identify an excessive bank angle condition prior to stall buffet.

Sideslip should be clearly indicated to the flight crew (e.g. split trapezoid on attitude indicator), and an indication of excessive sideslip should be provided.

A.1.2 Continued function of primary flight information (including standby) in conditions of unusual attitudes or in rapid maneuvers

Primary flight information must continue to be displayed in conditions of unusual attitudes or in rapid maneuvers (25.1303). The pilot must also be able to rely on primary or standby instrument information for recovery in all attitudes and at the highest pitch, roll and yaw rates that may be encountered (25.1333).

In showing compliance with the requirements of 14 CFR §§ 25.1301(d) and 25.1309(a), (b), (c) and (d), the analysis and test program must consider the following conditions that might occur due to pilot action, system failures or external events:

- abnormal attitude (including the airplane becoming inverted);
- excursion of any other flight parameter outside protected flight boundaries; or
- flight conditions that may result in higher than normal pitch, roll or yaw rates.

For each of the conditions identified above, primary flight displays and standby indicators must continue to provide useable attitude, altitude, airspeed and heading information and any other information that the pilot may require to execute recovery from the unusual attitude and/or arrest the higher than normal pitch, roll or yaw rates.

A.2 Airspeed and Altitude

Airspeed and altitude displays should be able to convey to the flight crew a quick-glance sense of the present speed or altitude. Conventional round-dial moving pointer displays inherently give some of this sense that may be difficult to duplicate on moving scales. Scale length is one attribute related to this quick-glance capability. The minimum visible airspeed scale length found acceptable for moving scales has been 80 knots; since this minimum is dependent on other scale attributes and airplane operational speed range, variations from this should be verified for acceptability.

Altimeters present special design problems in that: (1) the ratio of total usable range to required resolution is a factor of 10 greater than for airspeed or altitude, and (2) the consequences of losing sense of context of altitude can be detrimental. The combination of altimeter scale length and markings, therefore, should be adequate to allow sufficient resolution for precise manual altitude tracking in level flight, as well as enough scale length and markings to reinforce the flight crew's sense of altitude and to allow sufficient look-ahead room to adequately predict and accomplish level-off. Addition of radio altimeter information on the scale so that it is visually related to ground position may be helpful in giving low altitude awareness.

Airspeed scale markings that remain relatively fixed (such as stall warning, VMO/MMO), or that are configuration dependent (such as flap limits), should be displayed to provide the flight crew a quick-glance sense of speed. The markings should be predominant enough to confer the quick-glance sense information, but not so predominant as to be distracting when operating normally near those speeds (e.g., stabilized approach operating between stall warning and flap limit speeds).

Low speed awareness cues should provide adequate visual cues to the pilot that the airspeed is below the reference operating speed for the airplane configuration (i.e., weight, flap setting, landing gear position, etc.); similarly, high speed awareness cues should provide adequate visual cues to the pilot that the airspeed is approaching an established upper limit that may result in a hazardous operating condition.

- The cues should be readily distinguishable from other markings such as V-speeds and speed targets (bugs). The cues should indicate not only the boundary value of speed limit, but must clearly distinguish between the normal speed range and the unsafe speed range beyond those limiting values CFR §§ 25.1545. Cross-hatching may be acceptable to provide delineation between zones of different meaning.

- The display requirements for airspeed awareness cues are in addition to other alerts associated with exceeding high and low speed limits, such as the stick shaker and aural overspeed warning.

Airspeed reference marks (bugs) on conventional airspeed indicators perform a useful function, and the implementation of them on electronic airspeed displays is encouraged. Computed airspeed/angle-of-attack reference marks (bugs) such as Vstall, Vstall warning, V1, VR, V2, flap limit speeds, etc., displayed on the airspeed scale will be evaluated for accuracy. Provision should be incorporated for a reference mark that will reflect the current target airspeed of the flight guidance system. This has been required in the past for some systems that have complex speed selection algorithms, in order to give the flight crew adequate information required by § 25.1309(c) for system monitoring.

Numeric only indications of airspeed and altitude have been accepted during specific phases of flight (e.g. HUD during approach) in combination with other cues (e.g. acceleration) in order to reduce display clutter. If a numeric only indication of airspeed/altitude is provided, there should still remain a system level awareness of airspeed/altitude, airspeed/altitude trends, deviations from selected airspeed/altitude targets, low and high airspeed limits, and selected airspeed/altitude setting changes.

Scale units marking for air data displays incorporated into PFDs are not required ("knots," "airspeed" for airspeed, "feet," "altitude" for altimeters) as long as the content of the readout remains unambiguous. For altimeters with the capability to display in both English and Metric units, the scale and primary present value readout should remain scaled in English units with no units marking required; the Metric display should consist of a separate present value readout that does include units marking.

Airspeed scale graduations found to be acceptable have been in 5-knot increments with graduations labeled at 20-knot intervals. In addition, a means to rapidly identify a change in airspeed (e.g. speed trend vector or acceleration cue) should be provided; if trend or acceleration cues are used, or a numeric present value readout is incorporated, scale markings at 10-knot intervals have been found acceptable.

Minimum altimeter graduations should be in 100-foot increments with a present value readout, or 50-foot increments with a present value index only. Due to operational requirements, it is expected that airplanes without either 20-foot scale graduations, or a readout of present value, will not be eligible for Category II low visibility operation with barometrically determined decision heights.

Vertically oriented moving scale airspeed indication is acceptable with higher numbers at the top or bottom if no airspeed trend or acceleration cues are associated with the speed scale. Such cues should be oriented so that increasing energy or speed results in upward motion of the cue. To be consistent with this convention, airspeed scales with these cues should have the high speed numbers at the top. Speed, altitude, or vertical rate trend indicators should have appropriate hysteresis and damping to be useful and non-distracting. Evaluation should include turbulence expected in service.

A.3 Vertical Speed

The display range of Vertical Speed (or rate of climb) indications should be consistent with the climb/descent performance capabilities of the aircraft. If the RA is integrated with the primary vertical speed indication, the range of vertical speed indication should be sufficient to display the red and green bands for all TCAS resolution advisory (RA) information.

A.4 Flight Path Vector / Symbol

The display of Flight Path Vector (FPV or velocity vector) or Flight Path Angle (FPA) cues on the primary flight display is not required, but may be included in many designs.

Definition of terms regarding the display of flight path:

- Earth Referenced System – Inertial-based system which provides an inertially-derived display of flight path through space. In a descent, an earth-referenced system will indicate point of impact (i.e. runway touchdown point) if displayed.
- Air Mass System – An air mass based system which provides a heading/airspeed/vertical velocity derived flight path presentation. It depicts the flight path through an air mass, will not account for air mass disturbances such as wind drift and windshear, and therefore cannot be relied on to show the point of impact on the earth's surface.
- Flight Path Angle (FPA) (also known as a Flight Path Symbol or "caged" Flight Path Vector in various designs) - A dynamic symbol displayed on an attitude display that depicts the vertical angle relative to the artificial horizon, in the pitch axis, that the airplane is moving. A flight path angle is the vector resultant of the forward velocity and the vertical velocity. For most designs, the FPA is earth referenced, though some use air mass vectors. Motion of the FPA on the attitude display is in the vertical (pitch) axis only with no lateral motion.
- Flight Path Vector (FPV) (also known as Velocity Vector) - A dynamic symbol displayed on an attitude display that depicts the vector resultant of real-time flight path angle (vertical axis) and lateral angle relative to airplane heading created by wind drift and slip/skid. For most designs, the FPV is earth referenced, though some use air mass vectors which cannot account for wind effects.
- HUD (Heads Up Display) - A display system that projects primary flight information (e.g., attitude, air data, guidance, etc.) on a transparent screen (combiner) in the pilot's forward field of view, between the pilot and the windshield. This allows the pilot to simultaneously use the flight information while looking along the forward path out the windshield, without scanning the head down displays. The flight information symbols should be presented as a virtual image focused at optical infinity. Attitude and flight path symbology needs to be conformal (i.e., aligned and scaled) with the outside view.

- HDD (Heads Down Display) - Aircraft primary flight display located on the aircraft main instrument panel directly in front of the pilot in the pilot's primary field of view. The HDD is located below the windscreen and requires the flight crew to look below the glareshield in order to use the HDD to fly the aircraft.
- FPV/FPA-referenced Flight Director (FD) - HUD or HDD flight director cue in which the pilot "flies" the FPV/FPA cue to the FD command in order to comply with flight guidance commands. This is different from attitude FD guidance where the pilot "flies" the aircraft (i.e., pitch, boresight) symbol to follow pitch and roll commands.

The FPV symbol is essential to certain Head-Up Display (HUD) applications. FPV display on the HUD should be conformal with the outside view when within the HUD field of view. During flight situations with large bank, pitch and/or wind drift angles, the movement of the FPV may be limited by the available display field-of-view. In some designs, the pilot can manually cage the FPV which restricts its motion to the vertical axis, thereby making it an FPA.

The FPV or FPA indication may also be displayed on the HDD. In some HDD applications, the FPV or FPA is the primary control and tracking cue for controlling the airplane during most phases of flight. Even though an FPV or FPA indication may be used as a primary flight control parameter, the attitude pitch and roll symbols (i.e., waterline or boresight) which are still required primary indications by 14 CFR §25.1303 must still be prominently displayed. In dynamic situations, constant availability of attitude or flight path control parameters is required.

Considerations for presentation of FPV/FPA; If the FPV/FPA is used as the primary means to control the airplane in pitch and roll, the FPV/FPA system design must allow pilots to control and maneuver the airplane with a level of safety that is at least equal to traditional designs based on attitude (CFR §§ 25.1333(b)).

Aircraft designs may exist where the HUD is a FPV presentation and the HDD is a FPA presentation. For these situations, some correlation between the HUD FPV display and the PFD FPA display should exist. Vertical axis presentation of FPV/FPA should be consistent. The pilot should be able to interpret and respond to them similarly.

It should be easy and intuitive to perform cognitive switching between FPV/FPA and attitude when necessary. Primary Flight Display of FPV/FPA symbology must not interfere with the display of attitude and there must always bebe attitude symbology at the top center of the pilot's primary field of view, as required by 14CFR 25.1321.

Airplane designs which display flight path symbology on the HUD and the HDD should use consistent symbol shapes (i.e., the HUD FPV symbol looks like the HDD FPV).

In cases where an FPV is displayed head up and an FPA head down, the symbols for each should not have the same shape. When different types of flight path indications may be displayed, head up and/or head down, the symbols should be easily distinguished to avoid any misinterpretation by the flight crew members.

The normal FPV, the field-of-view limited FPV and the caged FPV (i.e.,FPA) should each have a distinct appearance, so that the pilot is aware of the restricted motion, or non-conformality.

Implementation of Air Mass based FPV/FPA presentations should account for inherent limitations of air mass flight path computations.

Considerations for Flight Director Guidance Based on FPV/FPA;

FPV/FPA based flight directors should provide some lateral movement to the lateral flight director guidance cue during bank commands.

To show compliance with §25.1303(b)(5), §25.1301(a), and §25.143(b), the FPV/FPA FD design must:
1. Have no characteristics that may lead to oscillatory control inputs.
2. Provide sufficiently effective and salient cues to support all expected maneuvers in longitudinal, lateral, and directional axes.
3. Have no inconsistencies between cues provided on the HUD and HDD displays that may lead to pilot confusion or have adverse affects on pilot performance.

Performance and system safety requirements for flight guidance systems (e.g., FGS, Category II/III, takeoff) are found in Advisory Circulars 25.1329B, 120-29A and 120-28D, and CS-AWO.

Appendix B: Powerplant Indications

To comply with a provision of §25.1305 a display should provide all the instrument functionality of a full time dedicated analog type instrument as intended when the rule was adopted (ref. AC20-88A). The design flexibility and conditional adaptability of modern displays were not envisioned when §25.1305 "Powerplant instruments" and §25.1549 "Powerplant and auxiliary power unit instruments" were initially adopted. In addition, the capabilities of modern control systems to automate and complement flight crew functions were not envisioned. In some cases these system capabilities obviate the need for a dedicated full-time analog type instrument.

When making a finding, all uses of the affected displays should be taken into consideration, including:

(1) Flight deck indications to support the approved operating procedures [re: §25.1585],

(2) Indications as required by the powerplant system safety assessments [re: §25.1309]

(3) Indications required in support of the instructions for continued airworthiness [re: §25.1529]

Example:
Compliance with §25.1305(c)(3) for the engine N2 rotor was originally achieved by means of a dedicated full time analog instrument. This provided the continuous monitoring capability required to:

- support engine starting (e.g. typically used to identify fuel on point);
- support power setting (e.g. sometimes used as primary or back up parameter);
- "give reasonable assurance that those engine operating limitations that adversely affect turbine rotor structural integrity will not be exceeded in service" as required by §25.903(d)(2);
- provide the indication of normal, precautionary and limit operating values required by §25.1549; as well as
- support detection of unacceptable deterioration in the margin to operating limits and other abnormal engine operating conditions as required to comply with §§25.901, 25.1309, etc.

As technology evolved Full Authority Digital Engine Controls (FADECs) were introduced. FADECs were designed with the ability to monitor and control engine N2 rotor speed as required to comply with §25.903(d)(2). Additionally, engine condition monitoring programs were introduced and used to detect unacceptable engine deterioration. Flight deck technology evolved such that indications could be displayed automatically to cover abnormal engine operating conditions. The combination of these developments obviated the need for a full time analog N2 rotor speed indication.

B.2 Additional Design Guidelines

Safety-related engine limit exceedances should be indicated in a clear and unambiguous manner. Flight crew alerting is addressed in 14CFR/CS §25.1322.

If an indication of significant thrust loss is provided it should be presented in a clear and unambiguous manner.

The following design guidelines are to be considered in addition to the failure conditions listed in Section 6.5.7:

1) For single failures leading to the non-recoverable loss of any indications on an engine, sufficient indications should remain to allow continued safe operation of the engine [ref. §25.901(b)(2), §25.901(c), §25.903(d)(2)]
2) For engine indications that are required during engine re-start, they should be readily available after an engine out event. (ref. §25.901(b)(2), §25.901(c) §25.903(d)(2), §25.903(e), §25.1301, §25.1305 §25.1309).

Pratt & Whitney
400 Main Street
East Hartford, CT 06108

Pratt & Whitney
A United Technologies Company

May 11, 2010

Federal Aviation Administration
800 Independence Avenue, SW
Washington, D.C. 20591

Attention: Ms. Margaret Gilligan, Associate Administrator for Aviation Safety

Subject: ARAC Recommendation, Avionics Systems Harmonization Working Group

References: 1. ARAC Tasking, Federal Register, April 23, 2002
2. ARAC TAEIG letter to Avionics Systems HWG, March 3, 2009

Dear Peggy,

The Transport Airplane and Engine Issues Group and the Avionics System Harmonization Working Group are pleased to submit the attached proposed new appendices to AC25-11A to the FAA as an ARAC recommendation. These proposed appendices address Weather Related Displays and Head-Up Displays in accordance with references 1 and 2. The Avionics HWG report was unanimously approved by TAEIG for transmittal to the FAA at our April 14, 2010 meeting.

Also attached are comments from TAEIG members Boeing and Bombardier providing some additional comments for FAA consideration. Please note that the Working Group has expressed their desire to assist the FAA in review and disposition of any public comments on the proposed Advisory Material.

Sincerely yours,

Craig R. Bolt

C. R. Bolt
Assistant Chair, TAEIG

Copy: Mike Kaszycki – FAA-NWR
Clark Badie – Honeywell
James Wilborn – FAA-NWR
Suzanne Masterson – FAA NWR
Ralen Gao – FAA-Washington, D.C. – Office of Rulemaking

U.S. Department
of Transportation
**Federal Aviation
Administration**

800 Independence Ave., SW.
Washington, DC 20591

Mr. Craig R. Bolt
Assistant Chair, Aviation Rulemaking
Advisory Committee
Pratt & Whitney
400 Main Street, Mail Stop 162-14
East Hartford, CT 06108

Dear Mr. Bolt:

This is in reply to your May 11, 2010 letter. Your letter transmitted to the FAA the Aviation Rulemaking Advisory Committee's (ARAC) recommendations regarding AC/AMC 25-11A for Weather Related Displays and Head-Up Displays (HUD). I understand that members of the Avionics System Harmonization Working Group (ASHWG) reached consensus and the report was approved unanimously by the Transport Airplane and Engine Issues Group (TAEIG).

I wish to thank the ARAC, particularly the members associated with TAEIG and its ASHWG that provided resources to develop the report and recommendation. The report will be placed on the ARAC website at: http://www.faa.gov/regulations_policies/rulemaking/committees/arac/.

We consider your submittal of the ASHWG report as completion of tasking from our April 23, 2002 tasking statement (67 FR 19796). We will keep the committee apprised of the agency's efforts on this recommendation through the FAA report at future ARAC meetings.

Sincerely,

Pamela Hamilton-Powell
Director, Office of Rulemaking

AC 25-11A Head-Up Display Appendix

1 INTRODUCTION

The material provided in this appendix provides additional guidance related to the unique aspects and characteristics, the design, analysis, testing, and definition of intended functions of head-up displays (HUD) for transport category airplanes.

In most applications, the HUD provides an indication of primary flight references which allow the pilot to rapidly evaluate the aircraft attitude, energy status, and position during the phases of flight for which the HUD is designed. A common objective of HUD information presentation is to enhance pilot performance in such areas as the transition between instrument and visual flight in variable outside visibility conditions. HUDs may be used to display enhanced and synthetic vision imagery, however the scope of this appendix does not include specific guidance for systems that provide this imagery.

This appendix addresses HUDs which are designed for a variety of different operational concepts and intended functions. It includes guidance for HUDs that are intended to be used as a supplemental display, where the HUD contains the minimum information immediately required for the operational task associated with the intended function. It also addresses HUDs that are intended to be used effectively as primary flight displays. This appendix addresses both the installation of a single HUD, typically for use by the left-side pilot, as well as special considerations related to the installation and use of dual HUDs, one for each pilot. These dual HUD special considerations will be called out in the appropriate sections which follow.

For guidance associated with specific operations using a HUD, such as low visibility approach and landing operations, see the relevant requirements and guidance material (e.g. CS-AWO, AC120-28D).

Additional guidance for the design and evaluation of HUDs can be found in ARP 5288, AS 8055 and ARP 5287.

2 HUD FUNCTION

The applicant is responsible for identifying the intended function of the HUD. The intended function should include the operational phases of flight, concept of operation, including how, when, and for what purpose the HUD is intended to be used. For example, the HUD systems may provide a head-up display of situational information and/or guidance information that may be used during all phases of flight.

2.1 Primary Flight Information

If the HUD is providing primary flight information, its primary flight information should be presented to allow easy recognition by the pilot while causing no confusion due to ambiguity with similar information presented on other aircraft flight deck displays.

If a HUD displays primary flight information, it is considered the de facto primary flight information while the pilot is using it, even if it is not the pilot’s sole display of this information.

Primary flight information displayed on the HUD should comply with all the requirements associated with such information in Part 25 (e.g., §§ 25.1303(b) and 25.1333(b)). The requirements for arranging primary flight information are specified in § 25.1321(b). For specific guidance regarding the display of primary flight information see the main body of this AC and also Appendix 1.

2.2 Other Information

Other information displayed on a HUD may be dependent on the phases of flight and flight operations supported by the HUD. This additional information is mainly related to the display of command guidance or situational information.

For example, if the HUD is to be used to monitor the autopilot, the following information should be displayed:

a. Situation information based on independent raw data;
b. Autopilot operating mode;
c. Autopilot disconnect warning (visual).

Additional information should also be displayed if required to enable the pilot to perform aircraft maneuvers during phases of flight for which the HUD is approved. These may include:

a. Flight path indication;
b. Target airspeed references and speed limit indications;
c. Target altitude references and altitude awareness (e.g., DH, MDA) indications;
d. Heading or course references.

2.3 Head-Up to Head-Down Transition

Events that may lead to transition between the HUD and the Head Down Display (HDD) should be identified and scenarios developed for evaluation (e.g., simulation, flight test). These scenarios should include systems failures, as well as events leading to unusual attitudes. Transition capability should be shown for all foreseeable modes of upset.

There may be differences between the way in which the head up and head down displays present information (e.g., flight path, situational, or aircraft performance information). Differences between the head up format and head down format should not create pilot confusion, misinterpretation, unacceptable delay, or otherwise hinder the pilot's transition between the two displays. HUD information should be easy to recognize and interpret by the pilot while causing no confusion due to ambiguity with similar information presented on other aircraft flight deck displays.

The HUD symbols should be consistent, but not necessarily identical, with those used on head down instruments to prevent misinterpretation or difficulty in transitioning between the two types of display. Similar symbols on the HUD and on the head down displays should have the same meaning.

The use of similar symbols on the HUD and on the head down displays to represent different parameters is not acceptable.

2.4 Dual HUDs

The applicant should define the operational concept for the use of the dual-HUD installation that details Pilot-Flying/Pilot-Not-Flying (PF/PNF) tasks and responsibilities in regards to using and monitoring head-down displays (HDD) and HUD's during all phases of flight. The Dual HUD concept of operation should specifically address the simultaneous use of the HUD by both pilots during each phase of flight, as well as cross cockpit transfer of control.

Single HUD installations where the pilot is likely to use the HUD as a primary flight reference rely on the fact that the PNF will monitor, full-time, the head-down instruments and alerting systems, for failures of systems, modes, and functions not associated with primary flight displays or HUD.

For the simultaneous use of dual HUDs, the applicant should demonstrate that the flight crew is able to maintain an equivalent level of awareness of key information not displayed on the HUD (e.g. powerplant indications, alerting messages, aircraft configuration indications).

The operational concept, defined by the applicant and used during the piloted evaluation of the installation, should account for the expected roles and responsibilities of the PF and the PNF, considering the following:

- When a pilot is using a HUD as the PFD, the visual head down indications may not receive the same level of vigilance by that pilot, compared to a pilot using the head down PFD.
- How the scan of the head down instruments is ensured during all phases of flight, and if not, what compensating design features are needed to help the flightcrew maintain awareness of key information (e.g., powerplant indications, alerting messages, aircraft configuration indication) not displayed on the HUD.
- Which pilot is expected to maintain a scan of head down instrument indications and how often. For any case where the scan of head down information is not full-time for at least one pilot, the design should have compensating design features which ensure an equivalent level of timeliness and awareness of the information provided by the head down visual indications.
- Cautions and warnings, if the visual information, equivalent to the head down PFD indications, is not presented in the HUD, the design should have compensating features that ensure the pilot using the HUD is made aware with no additional delay and able to respond with no reduction of task performance or degraded safety

For those phases of flight where airworthiness approval is predicated on the use of the HUD, or when it can be reasonably expected that the pilot will operate primarily by reference to the HUD, the objective is to not redirect attention of the pilot flying to another display when an immediate maneuver is required (e.g., resolution advisory, windshear). The applicant should either provide in the HUD the guidance, warnings, and annunciations of certain systems, if installed, such as a Terrain Awareness and Warning System (TAWS), or a traffic alert and collision avoidance system (TCAS) and a wind shear detection system, or provide compensating design features (e.g., a combinations of means such as control system protections and an unambiguous reversion message in the HUD) and procedures that ensure the pilot has equivalently effective visual information for timely awareness and satisfactory response to these alerts.

A global (re-)assessment of the alerting function should be performed to assess the HUDs alerting design and techniques together with the Alerting attention getting (visual MW and MC/aural) and other alerting information in the flight deck to ensure that timely crew awareness and response are always achieved when needed.

3 INSTALLATION

3.1 HUD Field of View

The design of the HUD installation should provide adequate display field-of-view in order for the HUD to function as intended in all anticipated flight attitudes, aircraft configurations, or environmental conditions, such as crosswinds, for which it is approved. All airworthiness and operational limitations should be specified in the AFM.

The optical characteristics of the HUD make the ability to fully view essential flight information more sensitive to the pilot's eye position, compared to head down displays. The HUD design eye-box is a three dimensional volume, specified by the manufacturer, within which display visibility requirements are met. For compliance to §§ 25.773 and 25.1301, whenever the pilot's eyes are within the design eyebox, the required flight information will be visible in the HUD. The minimum monocular field of view (FOV) required to display this required flight information, should include the center of the FOV and must be specified by the manufacturer.

The fundamental requirements for instrument arrangement and visibility that are found in §§ 25.1321, 25.773 and 25.777 apply to these devices. Section 25.1321 requires that each flight instrument for use by any pilot be plainly visible at that pilot's station, with minimum practicable deviation from the normal position and forward line of vision. Advisory Circular (AC) 25.773-1 defines the Design Eye Position (DEP) as a single point that meets the requirements of §§ 25.773 and 25.777. For certification purposes, the DEP is the pilot's normal seated position, and fixed markers or other means should be installed at each pilot station to enable the pilots to position themselves in their seats at the DEP for an optimum combination of outside visibility and instrument scan. The Design Eye Box should be positioned around the Design Eye Position.

The visibility of the displayed HUD symbols must not be unduly sensitive to pilot head movements in all expected flight conditions. In the event of a total loss of the display as a result of a head movement, the pilot must be able to regain the display rapidly and without difficulty.

The lateral and vertical dimensions of the eyebox represent the total movement of a monocular viewing instrument with a 1/4 in. (6.35 mm) entrance aperture (pupil). The eye-box longitudinal dimension represents the total fore-aft movement over which the requirement of this specification is met. (Reference SAE AS8055).

The HUD design eyebox should be laterally and vertically positioned around the respective pilot's design eye position (DEP), and be large enough that the required flight information will be visible to the pilot at the minimum displacements from the DEP listed below. When the HUD is a Primary Flight Display, or when airworthiness approval is predicated on the use of the HUD, or when the pilot can be reasonably expected to operate primarily by reference to the HUD, larger minimum design eyebox dimensions, than those shown below, may be necessary.

Lateral:	1.5 inches left and right from the DEP (three inches wide)
Vertical:	1.0 inches up and down from the DEP (two inches high)
Longitudinal:	2.0 inches fore and aft from the DEP (4 inches deep)

The HUD installation must comply with §§ 25.1321, 25.773 and accommodate pilots from 5'2" to 6'3" tall (per 25.777), seated with seat belts fastened and positioned at the DEP.

3.2 Obstruction of View

When installed, whether deployed or not, the HUD equipment must not create additional significant obstructions to either pilot's compartment view (§ 25.773). The equipment must not restrict either pilot's view of any controls, indicators or other flight instruments.

The HUD should not significantly degrade the necessary pilot compartment view of the outside world for normal, non-normal, or emergency flight maneuvers during any phase of flight for a pilot seated at the DEP. The HUD should be evaluated to ensure that it does not significantly affect the ability of any crewmember to spot other traffic, distinctly see approach lights, runways, signs, markings, or other aspects of the external visual scene.

The optical performance of the HUD must not degrade, distort or detract from the pilot's view of external references or in regards to seeing and avoiding other aircraft such that it would not enable them to safely perform any maneuvers within the operating limits of the airplane (§25.773). Where the windshield optically modifies the pilot's view of the outside world, the conformal HUD symbols must be optically consistent with the perceived outside view. The combination of the windshield and the HUD must meet the requirements of § 25.773(a)(1).

The optical qualities of the HUD should be uniform across the entire field of view. When viewed by both eyes from any off-center position within the eyebox, non-uniformities shall not produce perceivable differences in binocular view. Additional guidance is provided in ARP 5288.

3.3 Crew Safety

The HUD system must be designed and installed to prevent the possibility of pilot injury in the event of an accident or any other foreseeable circumstance such as turbulence, hard landing, bird strike, etc. The installation of the HUD, including overhead unit and combiner, must comply with the head injury criteria (HIC) of § 25.562 (c)(5). Additionally, the HUD installation must comply with the retention requirements of § 25.789(a) and occupant injury requirements of §§ 25.785 (d) and (k).

For a dual HUD installation, there is the potential for both pilots to experience an incapacitating injury as a result of flight or gust loads. This becomes a safety of flight issue, since the entire flightcrew would be incapacitated. The types of injuries of concern may be long duration, low impact, high load, as opposed to the high impact, short duration injuries assessed by HIC. A dedicated method of compliance may be needed should analysis of the installation geometry indicate that flight or gust loads will produce occupant contact with the HUD installation.

For compliance to §§ 25.803, 25.1307, 25.1411 and 25.1447, the HUD installation must not interfere with or restrict the use of other installed equipment such as emergency oxygen masks, headsets, or microphones. The installation of the HUD must not adversely affect the emergency egress provisions for the flight crew, or significantly interfere with crew access. The system must not hinder the crew's movement while conducting any flight procedures.

3.4 HUD Controls

For compliance to § 25.777, the means of controlling the HUD, including its configuration and display modes, must be visible to, identifiable, accessible, and within the reach of, the pilots from their normal seated position. For compliance to §§ 25.777, 25.789 and 25.1301, the position and movement of the HUD controls must not lead to inadvertent operation. For compliance to § 25.1381, the HUD controls must be adequately illuminated for all normal ambient lighting conditions, and must not create any objectionable reflections on the HUD or other flight instruments. Unless a fixed level of illumination is satisfactory under all lighting conditions, there should be a means to control its intensity.

To the greatest extent practicable, the HUD controls should be integrated with other associated flight deck controls, to minimize the crew workload associated with HUD operation and to enable flightcrew awareness.

HUD controls, including the controls to change or select HUD modes, should be implemented to minimize pilot workload for data selection or data entry and allow the pilot to easily view and perform all mode control selections from his seated position.

4 INFORMATION PRESENTATION

4.1 Displayed Information

The HUD information display requirements will depend on the intended function of the HUD. Specific guidance for displayed information is contained within the main body and Appendix 1 of this AC. In addition, the following sections provide guidance related to unique characteristics of the HUD. As in the case of other flight deck displays, new and/or novel display formats may be subject to an Authority human factors pilot interface evaluation(s).

4.1.1 Alternate Formats of Displaying Primary Flight Information

There may be certain operations and phases of flight during which certain primary flight reference indications in the HUD do not need to have the analog cues for trend, deviation, and quick glance awareness that would normally be necessary. For example, during the precision approach phase, HUD formats have been accepted that provide a digital only display of airspeed and altitude. Acceptance of these displays has been predicated on the availability of compensating features that provide clear and distinct warning to the flight crew when these and certain other parameters exceed well-defined tolerances around the nominal approach state (e.g., approach warning), and these warnings have associated procedures that require the termination of the approach.

Formats with digital-only display of primary flight information (e.g., airspeed, altitude, attitude, heading) should be demonstrated to provide at least:

- a satisfactory level of task performance,
- a satisfactory awareness of proximity to limit values, like Vs, VMO and VFE, or
- a satisfactory means to avoid violating such limits.

If a different display format is used for go-around than that used for the approach, the format transition should occur automatically as a result of the normal go-around or missed approach procedure.

Changes in the display format and primary flight data arrangement should be minimized to prevent confusion and to enhance the pilots' ability to interpret vital data.

4.1.2 Aircraft Control Considerations

For those phases of flight where airworthiness approval is predicated on the use of the HUD, or when it can be reasonably expected that the pilot will operate primarily by reference to the HUD, the HUD should adequately provide:

- information to permit instant pilot evaluation of the airplane's flight state and position. This should be shown to be adequate for manually controlling the airplane, and for monitoring the performance of the automatic flight control system. Use of the HUD for manual control of the airplane and monitoring of the automatic flight control system, should not require exceptional skill, excessive workload, or excessive reference to other flight displays.

- cues for the pilot to instantly recognize unusual attitudes and shall not hinder its recovery. If the HUD is designed to provide guidance or information for recovery from upsets or unusual attitudes, recovery steering guidance commands should be distinct from, and not confused with, orientation symbology such as horizon “pointers.” This capability should be shown for all foreseeable modes of upset, including crew mishandling, autopilot failure (including "slowovers"), and turbulence/gust encounters.

4.1.3 Airspeed Considerations

As with other electronic flight displays, the HUD airspeed indications may not typically show the entire range of airspeed. Section 25.1541 (b)(2) of the Federal Aviation Regulations states: "The airplane must contain - Any additional information, instrument markings, and placards required for the safe operation if there are unusual design, operating, or handling characteristics. "

Low speed awareness cues presented on the HUD should provide adequate visual cues to the pilot that the airspeed is below the reference operating speed for the airplane configuration (i.e., weight, flap setting, landing gear position, etc.); similarly, high speed awareness cues should provide adequate visual cues to the pilot that the airspeed is approaching an established upper limit that may result in a hazardous operating condition.

The cues should be readily distinguishable from other markings such as V-speeds and speed targets (bugs). The cues should not only indicate the boundary value of speed limit, but also clearly distinguish between the normal speed range and the unsafe speed range beyond those limiting values. Cross-hatching may be acceptable to provide delineation between zones of different meaning.

4.1.4 Flight Path Considerations

An indication of the aircraft’s velocity vector, or flight path vector, is considered essential to most HUD applications. Earth-referenced flight path display information provides an instantaneous indication of where the aircraft is actually going. During an approach this information can be used to indicate the aircraft’s impact or touchdown point on the runway. The earth referenced flight path will show the effects of wind on the motion of the airplane. The flight path vector can be used by the pilot to set a precise climb or dive angle relative to the conformal outside scene or relative to the HUD’s flight path (pitch) reference scale and horizon displays. In the lateral axis the flight path symbols should indicate the aircraft track relative to the boresight.

Air mass derived flight path may be displayed as an alternative, but will not show the effects of wind on the motion of the airplane. In this case the lateral orientation of the flight path display represents the aircraft’s sideslip while the vertical position relative to the reference symbol represents the aircraft’s angle of attack.

The type of flight path information displayed (e.g., earth referenced, air mass) may be dependent on the operational characteristics of a particular aircraft and the phase of flight during which the flight path is to be displayed.

4.1.5 Attitude Considerations

An accurate, easy, quick glance interpretation of attitude by the pilot should be possible for all unusual attitude situations and command guidance display configurations. The pitch attitude display should be such that during all maneuvers a horizon reference remains visible with enough margin to allow the pilot to recognize pitch and roll orientation. For HUDs that are capable of displaying the horizon conformally, display of a non-conformal horizon reference should be distinctly different than the display of a conformal horizon reference.

In addition, extreme attitude symbology and automatically decluttering the HUD at extreme attitudes has been found acceptable (extreme attitude symbology should not be visible during normal maneuvering).

When the HUD is designed not to be used for recovery from unusual attitude, there should be:

- compensating features (e.g., characteristics of the airplane and the HUD system),
- immediate direction to the pilot to use the head down PFD for recovery, and
- satisfactory demonstration of timely recognition and correct recovery maneuvers.

4.2 Display Compatibility

The content, arrangement and format of the HUD information should be sufficiently compatible and consistent with the head down displays to preclude pilot confusion, misinterpretation, or excessive cognitive workload. Transitions between the HUD and head down displays, whether required by navigation duties, failure conditions, unusual airplane attitudes, or other reasons, should not present difficulties in data interpretation or delays/interruptions in the flight crew's ability to manually control the airplane or to monitor the automatic flight control system.

The HUD and HDD formats and data sources need to be compatible to ensure that the same information presented on both displays have the same intended meaning. HUD and HDD parameters should be consistent to avoid misinterpretation of similar information, but the display presentations need not be identical.

Deviation from these guidelines may be unavoidable due to conflict with other information display characteristics or requirements unique to head up displays. These may include minimization of display clutter, minimization of excessive symbol flashing, and the presentation of certain information conformal to the outside scene. Deviations from these guidelines will require additional pilot evaluation.

The following should be considered:

(a) Symbols that have the same meaning should be the same format;

(b) Information (symbols) should appear in the same general location relative to other information;

(c) Alphanumeric readouts should have the same resolution, units, and labeling (e.g., the command reference indication for “vertical speed” should be displayed in the same foot-per-minute increments and labeled with the same characters as the head-down displays);

(d) Analogue scales or dials should have the same range and dynamic operation (e.g., a Glideslope Deviation Scale displayed head-up should have the same displayed range as the Glideslope Deviation Scale displayed head-down, and the direction of movement should be consistent);

(e) FGS modes (e.g. autopilot, flight director, autothrust) and state transitions (e.g. land 2 to land 3) should be displayed on the HUD, and except for the use of colour, should be displayed using consistent methods (e.g., the method used head-down to indicate a flight director mode transitioning from armed to captured should also be used head-up); and

(f) Information sources should be consistent between the HUD and the head-down displays used by the same pilot.

(g) When command information (i.e., flight director commands) is displayed on the HUD in addition to the head-down displays, the HUD depiction and guidance cue deviation “scaling” needs to be consistent with that used on the head-down displays. This is intended to provide comparable pilot performance and workload when using either head-up or head-down displays.

(h) The unique information concerning current HUD system mode, reference data, status state transitions, and alert information that is displayed to the pilot flying on the HUD, should also be displayed to the pilot not flying using consistent nomenclature to ensure unambiguous awareness of the HUD operation.

4.3 Indications and Alerts

In order to demonstrate compliance with 25.1322 and to the extent that most HUDs are currently single color (monochrome) devices, caution and warning information should be emphasized with the appropriate use of attention-getting properties such as flashing, outline boxes, brightness, size, and/or location to compensate for the lack of color coding. A consistent documented philosophy should be developed for each alert level and conflicts of meaning with head-down display format changes will need to be avoided.

Additional guidance is in AC 25.1329 and AC 25.1322 and the associated regulations.

4.4 Display Clutter

Clutter has been addressed elsewhere in this A(M)C. However, for a HUD, special attention is needed regarding the effects of clutter affecting the see-through characteristics of the display.

5 VISUAL CHARACTERISTICS

The following paragraphs highlight some areas, which are related to performance aspects that are specific to the HUD. ARP5288 and AS8055 provide performance guidelines for a head-up display. As stated in Chapter 3, the applicant should notify the Airworthiness Authority if any visual display characteristics do not meet the guidelines in AS8055 and ARP 5288.

5.1 Luminance Control

The display luminance (brightness) should be satisfactory in the presence of dynamically changing background (ambient) lighting conditions (0 to 10,000 fL per AS8055), so that the HUD data is visible to the pilot(s). To accomplish this, the HUD may have both manual and automatic luminance control capabilities. It is recommended that automatic control is provided in addition to the manual control. Manual control of the HUD brightness level should be available to the flight crew in order to provide the means to set a reference level for automatic brightness control. If automatic control for display brightness is not provided, it should be shown that a single manual setting is satisfactory for the range of lighting conditions encountered during all foreseeable operational conditions and against expected external scenes. Readability of the displays should be satisfactory in all foreseeable operating and ambient lighting conditions. AS8055 and ARP 5288 provide guidelines for contrast and luminance control.

5.2 Alignment

Proper HUD alignment is needed to match conformal display parameters as close as possible to the outside (real) world, depending on the intended function of those parameters.

If the HUD combiner is stowable, means should be provided to ensure that it is fully deployed prior to using the symbology for aircraft control. The HUD system shall provide means to alert the pilot if the position of the combiner causes normally conformal data to become misaligned in a manner that may result in display of misleading information.

The range of motion of conformal symbology can present certain challenges in rapidly changing and high crosswind conditions. In certain cases, the motion of the guidance and the primary reference cue may be limited by the field of view.

It should be shown that, in such cases, the guidance remains usable and that there is a positive indication that it is no longer conformal with the outside scene. It should also be shown that there is no interference between the indications of primary flight information and the flight guidance cues.

5.2.1 Symbol Positioning Accuracy (External)

External Symbol Positioning Accuracy, or Display Accuracy, is a measure of the relative conformality of the HUD display with respect to the real world view seen by the pilot through the combiner and windshield from any eye position within the HUD Eyebox. Display Accuracy is a monocular measurement, and, for a fixed field point, is numerically equal to the angular difference between the position of a real world feature as seen through the combiner and windshield, and the HUD projected symbology.

The total HUD system display accuracy error budget (excluding sensor and windshield errors) includes installation errors, digitization errors, electronic gain and offset errors, optical errors, combiner positioning errors, errors associated with the CRT and yoke (if applicable), misalignment errors, environmental conditions (i.e., temperature and vibration), and component variations. Optical errors are both head position and field angle dependent and are comprised of three sources: uncompensated pupil and field errors originating in the optical system aberrations, image distortion errors, and manufacturing variations. The optical errors are statistically determined by sampling the HUD FOV and Eyebox. (See 4.2.10 of SAE 8055 for a discussion of field of view and Eyebox sampling);

- The optical errors shall represent 95.4% (2 sigma) of all sampled points.
- The display accuracy errors are characterized in both the horizontal and vertical planes.
- Total display accuracy shall be characterized as the root-sum square (RSS) errors of these two component errors.

All display errors shall be minimized across the display field of view consistent with the intended function of the HUD. The following are the allowable display accuracy errors for a conformal HUD as measured from the HUD Eye Reference Point:

- HUD Boresight   <= 5.0 mrad
- <= 10° diameter   <= 7.5 mrad (2 Sigma)
- <= 30° diameter   <=10.0 mrad (2 Sigma)
- >30° diameter   < 10 mrad + kr[(FOV)(in degrees) - 30)] (2 Sigma)
  kr = 0.2 mrad of error per degree of FOV

The HUD manufacturer shall specify the maximum allowable installation error. In no case shall the display accuracy error tolerances cause hazardously misleading data to be presented to the pilot viewing the HUD.

5.2.2 Symbol Positioning Alignment

Symbols which are interpreted relative to each other shall be aligned to preclude erroneous interpretation of information. Symbols which are not interpreted relative to each other may overlap but shall not cause erroneous interpretation of display data, even when they overlap.

5.2.3 Combiner Position Alignment:

The HUD system shall provide a warning to the pilot if the position of the combiner causes conformal data to become hazardously misaligned.

5.3 Reflections and Glare

The HUD must be free of glare and reflections that could interfere with the normal duties of the minimum flight crew (per 14 CFR 25.1523 and 25.777).

5.4 Ghost Images

The visibility of ghost images within the HUD of external surfaces must be minimized so as not to impair the pilot's ability to use the display.

A ghost image is an undesired image appearing at the image plane of an optical system. Reflected light may form an image near the plane of the primary image. This may result in a false image of the object or an out-of-focus image of a bright source of light in the field of the optical system (e.g., a "ghost image").

5.5 Design Eye Position

The HUD Design Eye Position (DEP) must be the same as that defined for the basic cockpit in accordance with AC 25.773-1. The Design Eyebox must contain the DEP. The displayed symbols which are necessary to perform the required tasks must be visible to the pilot from the DEP and the symbols must be positioned such that excessive eye movements are not required to scan elements of the display.

5.6 Field Of View

The Field of View should be established by taking into consideration the intended operational environment and potential aircraft configurations.

5.7 Head Motion

The visibility of the displayed symbols must not be unduly sensitive to pilot head movements in all expected flight conditions. In the event of a total loss of the display as a result of a head movement, the pilot must be able to regain the display rapidly and without difficulty.

5.8 Accuracy and Stability

The system operation should not be adversely affected by aircraft manoeuvring or changes in attitude encountered in normal service.
The accuracy of positioning of symbols must be commensurate with their intended use. Motion of non-conformal symbols must be smooth, not sluggish or jerky, and consistent with aircraft control response. Symbols must be stable with no discernible flicker or jitter.

5.9 HUD Optical Performance

As far as practicable, the optical performance of the HUD must not degrade, distort or detract from the pilot's view of external references or of other aircraft. Where the windshield optically modifies the pilot's view of the outside world, the conformal HUD symbols must be optically consistent with the perceived outside view. The combination of the windshield and the HUD must meet the requirements of 14 CFR/CS 25.773(a)(1).

6 SAFETY ASPECTS

The installation of HUD systems in flight decks may introduce complex functional interrelationships between the pilots and other display and control systems. Consequently, a

Functional Hazard Assessment (FHA) which requires a top down approach, from an airplane level perspective, should be developed in accordance with FAR/CS 25.1309. Development of a FHA for a particular installation requires careful consideration of the role the HUD plays within the flight deck in terms of integrity of function and availability of function, as well the operational concept of the installation to be certified (dual vs single, type and amount of information displayed, etc.). Chapter 4 of this AC provides material that may be useful in supporting the FHA preparation.

All alleviating flight crew actions that are considered in the HUD safety analysis need to be validated for incorporation in the airplane flight manual procedures section or for inclusion in type-specific training.

Since the flight information displayed on the HUD is visible only to one pilot, and since in most cases, failures of flight parameters shown on the HUD are not independent of those shown on the same pilot's head down primary flight display, the HUD may not be a suitable means to comply with 25.1333(b) following loss of primary head down flight displays. The rule requires that at least one display of information essential to safety of flight remain available to the (both) pilots, not just one pilot.

7 CONTINUED AIRWORTHINESS

Depending on the type of operation and the intended function of the HUD, instructions for the continued airworthiness of a display system and its components have to be prepared to show compliance with §§ 25.1309 and 25.1529 (including Appendix H)

8 FLIGHT DATA RECORDING

The installation of HUDs has design aspects and unique operational characteristics requiring specific accident recording considerations. HUD guidance modes and status (in use or inoperative) and display declutter mode should be considered to be recorded to comply with § 25.1459(e) and 121.344.

Appendix W
Weather Displays

1. Background and Scope:

This appendix provides additional guidance for displaying weather information in the flight deck. Weather displays provide the flight crew with additional tools to help the flight crew make decisions based on weather information.

Sources of weather information may include, but would not be limited to: onboard, real-time weather, data-linked weather, turbulence information, pilot/air traffic reports, and may be displayed in a variety of graphical or text formats.

Because there are many sources of weather information, it is important that the applicant identify and assess the intended function for a particular source and display of weather information, and apply the guidance contained within this AC/AMC.

2. Key Characteristics

In addition to the general guidelines provided in this AC, there are unique aspects of the display of weather information so that the information is being used as intended.

A. The display should enable the flight crew to quickly, accurately, and consistently differentiate among sources of displayed weather, as well as differentiate between time-critical weather information and dated, non-time critical weather information.

B. Weather presentations (display format, the use of colors, labels, data formats, and interaction with other display parameters) should be clear and unambiguous and not result in a flight crew member's misunderstanding or misinterpretation of the weather information being displayed. Weather displays may use red and amber/yellow provided that all of the following criteria are met;

   1. The use of color is in compliance with 14 CFR/CS 25.1322, AC 25.1322, and this AC.
   2. The use of color is appropriate to the task and context of use, and,
   3. The proposed use does not affect the attention getting qualities of flight crew alerting and does not adversely affect the alerting functions across the flight deck, and,
   4. Color conventions (such as ARINC 708; AC 20-149) are utilized.

Note: AC 20-149 indicates an exclusion to the acceptability of DO-267A (paragraph 7.d) for part 25 airplanes.

C. If more than one source of weather information is available to the flight crew, an indication of the weather source selection should be provided.

D. If weather information is displayed as an overlay on an existing display format, both the weather information and the information it overlays should be readily distinguished and correctly interpreted from each other. It also should be consistent with the information it overlays, in terms of position, orientation, range, and altitude.

E. When simultaneously displaying multiple weather sources (e.g. weather radar and data link weather), each source should be clear and unambiguous and not result in a misunderstanding or misinterpretation of the displayed weather information by the flight crew. This is applicable also for symbols (e.g. winds aloft, lightning) having the same meaning from different weather information sources.

F. Fusion of sensor information to create a single weather image may be acceptable provided the fused weather information meets its intended function, and the fused information is shown to be in compliance with the guidance in this AC (e.g the pilot understands the source of the fused information). When fusing or overlaying multiple weather sources, the resultant combined image should meet its intended function despite any differences in image quality, projection, data update rates, data latency, or sensor alignment algorithms.

G. If weather information is displayed on the HUD, the guidelines of this AC including appendix H need to be considered.

H. When weather is not displayed in real time, some means to identify its relevance (e.g. time stamp or product age) should be provided. Presenting product age is particularly important when combining information from multiple weather products.

I. If a weather radar looping (animation) feature is provided, means to readily identify the total elapsed time of the image compilation should be provided, to avoid potential misinterpretation of the movement of the weather cells.

J. For products that have the ability to present weather for varying altitudes (e.g., potential or reported icing, radar, lightning strikes), information should be presented that allows the flight crew to distinguish or identify which altitude ranges are being presented.

K. Weather information may include a number of graphical and text information “features” or sets of information (e.g. text and graphical METARS, winds aloft) There should be a means to identify the meaning of each “feature” to ensure that the information is correctly used.

L. If the pilot or system has the ability to turn a weather source on and off, it should be clearly indicated when it is turned off.

M. When weather information is presented in a vertical situation display (VSD), it should be depicted sufficiently wide to contain the weather information that is relevant to the current phase of flight or flight path. In addition:

   1. Weather information displayed on VSD shall be accurately depicted with respect to the scale factors of the display (i.e., vertical and horizontal), all vertical path information displayed, including glide slope, approach path, or angle of descent.
   2. Consideration should be given to making the weather information display width consistent with the display width used by other systems, including Terrain Awareness and Warning System (TAWS), if displayed.

3. On-Board Weather Radar Information

On-Board Weather Radar may provide forward-looking weather detection, including windshear and turbulence detection.

The display of on-board weather radar information should be in accordance with the applicable portions of RTCA DO-220, “Minimum Operational Performance Standards for Airborne Weather Radar With Forward-Looking Windshear Capability.”

The weather display echoes from precipitation and ground returns should be clear, automatic, timely, concise and distinct for rapid pilot interpretation so flight crews can easily analyze and avoid areas of detected hazards. The radar range, elevation, and azimuth indications should provide sufficient indication to the flight crew to allow for safe avoidance maneuvers.

4. Predictive Windshear Information

The display of windshear information, if provided, should be clear, automatic, timely, concise and distinct for rapid pilot interpretation so flight crews can easily detect and avoid areas of windshear activity.

When a windshear threat is detected, the corresponding display may be automatically presented or selected by pilot action, at a range which is appropriate to identify the windshear threat. Pilot workload necessary for its presentation should be minimized and should not take more than one action when the cockpit is configured for normal operating procedures.

The display of a predictive windshear threat, including relative position and azimuth with respect to the nose of the airplane, should be presented in an unambiguous manner to effectively assist the flight crew in responding to the windshear threat; the symbol should be presented in accordance with DO-220.

The size and location of the windshear threat should be presented using a symbol that is sufficient to allow the pilot to recognize and respond to the threat

The range selected by the pilot for the windshear display should be sufficient to allow the pilot to distinguish the event from other displayed information. Amber radial lines may be used to extend from the left and right radial boundaries of the icon extending to the upper edge of the display.

5. Safety Aspects

Both the loss of weather information plus the display of misleading weather information should be addressed in the functional hazard assessment (FHA). In particular, this should only address failures of the display system that could result in loss of or misleading weather information, not the sensor itself.

In accordance with paragraph 4 of this AC, display of misleading weather radar includes the display of weather radar information that would lead the pilot to make a bad decision and introduce a potential hazard. Examples of misleading weather radar information include, but are not limited to: storm cells presented on the display that are not in the correct position, are at the wrong intensity, not displayed when they should be displayed, or mis-registered in the case of a combined (e.g fused) image.

Comment Response Template
for FAA Rulemaking/Guidance Documents

DOCUMENT TITLE:	AC 25-11A Appendix for Wx
COMMENTS PREPARED BY:	
Name: Boeing	Date: April 23, 2010

COMMENT #1 of 2	
Specific section of the proposed document that is of concern.	**Paragraph 2.J.** For products that have the ability to present weather for varying altitudes (e.g., potential or reported icing, radar, lightning strikes), information should be presented that allows the flight crew to distinguish or identify which altitude ~~ranges are being presented~~ **or altitude range applies to each feature**.
What is the proposed text?	
What about this proposed text do we want changed?	For products that have the ability to present weather for varying altitudes (e.g., potential or reported icing, radar, lightning strikes), information should be presented that allows the flight crew to distinguish or identify which altitude ~~ranges are being presented~~ **or altitude range applies to each feature**.
Why is the change justified?	Provides clearer description of acceptable means of compliance.
COMMENT #2 of 2	
Specific section of the proposed document that is of concern.	**Paragraph 2.L.** If the pilot or system has the ability to turn a weather source on and off, **there must be a clear means for the flight crew to determine if it is turned on or off** ~~it should be clearly indicated when it is turned off~~.
What is the proposed text?	
What about this proposed text do we want changed?	If the pilot or system has the ability to turn a weather source on and off, **there must be a clear means for the flight crew to determine if it is turned on or off** ~~it should be clearly indicated when it is turned off~~.
Why is the change justified?	Allows for a "Quiet Dark" flightdeck concept. Allows the uses a positive alpha/numeric display on the nav displays when wxr is turned ON, whether or not there is a wxr return, and blanks this indication when the wxr is turned off.

Comment Response Template
for FAA Rulemaking/Guidance Documents

DOCUMENT TITLE:	AC 25-11A Appendix for HUD

COMMENTS PREPARED BY:	
Name: Boeing	Date: April 23, 2010

COMMENT #1 of 5	
Specific section of the proposed document that is of concern.	Section 2.2, "c. Autopilot disconnect warning (Visual)".
What is the proposed text?	Recommend change it to: "c. Autopilot engage status"
What about this proposed text do we want changed?	c. Autopilot ~~disconnect warning (Visual)~~ engage status "
Why is the change justified?	Revised wording provides a more appropriate flightdeck design criteria.
COMMENT #2 of 5	
Specific section of the proposed document that is of concern.	Section 2.4 Dual HUDs, second paragraph on page 3.
What is the proposed text?	Recommended change - "For the simultaneous use of dual HUDs, ~~the applicant should demonstrate that~~ a means shall be provided so the flight crew is able to maintain an equivalent level of awareness of key information not displayed on the HUD."
What about this proposed text do we want changed?	For the simultaneous use of dual HUDs, ~~the applicant should demonstrate that~~ a means shall be provided so the flight crew is able to maintain an equivalent level of awareness of key information not displayed on the HUD.
Why is the change justified?	Provides language more appropriate for the applicant of the type design.
COMMENT #3 of 5	
Specific section of the proposed document that is of concern.	Section 2.4 Dual HUDs, first paragraph on page 3 of 12.
What is the proposed text?	Single HUD installations where the pilot is likely to use the HUD as a primary flight reference rely on the fact that the PNF will monitor, full-time, the head-down instruments and alerting systems, for failures of systems, modes, and functions not associated with primary flight displays or HUD.

What about this proposed text do we want changed?	Delete the text “full-time”.
Why is the change justified?	The PNF’s activities extend beyond simply monitoring head-down displays “full-time”, and include, for example; communication, checklist reading, tasks asked for by the PF and monitoring of the PF’s activities.
COMMENT #4 of 5	
Specific section of the proposed document that is of concern.	Paragraph 3.3 Crew Safety, on page 5 of 12.
What is the proposed text?	
What about this proposed text do we want changed?	The discussion of paragraph 3.3 on Crew Safety could benefit from a lead-in sentence that says something like: "Installation of HUD equipment brings into consideration regulations and hazard assessments not traditionally associated with Electronic Flight Deck Displays."
Why is the change justified?	The content of the rest of paragraph 3.3 is fine.
COMMENT #5 of 5	
Specific section of the proposed document that is of concern.	Paragraph 6 Safety Aspects, 3rd paragraph oh page 12 of 12.
What is the proposed text?	Since the flight information displayed on the HUD is visible only to one pilot, and since in most cases, failures of flight parameters shown on the HUD are not independent of those shown on the same pilot’s head down primary flight display, the HUD may not be a suitable means to comply with 25.1333(b) following loss of primary head down flight displays. The rule requires that at least one display of information essential to safety of flight remain available to the (both) pilots, not just one pilot.
What about this proposed text do we want changed?	The paragraph should not dismiss that a HUD could be a suitable means to comply with 25.1333(b).
Why is the change justified?	The discussion paragraph 6.0 on Safety Aspects (3rd paragraph on page 12) states that a HUD may not be a suitable means to comply with CFR 25.1333(b). We believe HUDs would not be a suitable means to comply with the required equipment described in CFR 121.305(k), but could be part of a totally satisfactory means of complying with 25.1333(b). We believe that even though the information displayed on any single HUD is visible to only one pilot, the information displayed therein satisfies the flight and navigation instrument requirements of 25.1303(b) and could be used to support the availability requirement of 25.1333(b). We don't believe the requirement of 25.1333(b), nor the safety assessment guidelines of AC 25-11A would lead one to conclude that loss of all flight instruments to one of the pilots must be extremely improbable. For example, It would not be catastrophic if the primary flight instruments to one pilot, and a centrally located standby display were both inoperative (an event that may not be extremely improbable), provided one crew member had a good display of primary flight instruments required by 25.1303(b), and which could conceivably be displayed on a HUD.

Pratt & Whitney
400 Main Street
East Hartford, CT 06108

Pratt & Whitney
A United Technologies Company

May 11, 2010

Federal Aviation Administration
800 Independence Avenue, SW
Washington, D.C. 20591

Attention: Ms. Margaret Gilligan, Associate Administrator for Aviation Safety

Subject: ARAC Recommendation, Airplane-Level Safety Analysis Working Group

Reference: ARAC Tasking, Federal Register, March 21, 2006

Dear Peggy,

The Transport Airplane and Engine Issues Group and the Airplane-Level Safety Analysis Working Group are pleased to submit the attached report and associated proposals for new regulatory language and advisory material to the FAA as an ARAC recommendation. This report addresses the referenced tasking to provide information about specific risk assessments. Specific areas addressed in the report include Latent failures, Aging & Wear, MMEL and Flight and Diversion Time. The Working Group had consensus in the areas of Aging & Wear and MMEL. The Flight and Diversion Time area had one dissenting opinion in the WG, while in the area of Latent failures there were 7 dissenting opinions. These are clearly documented in the report. The report was unanimously approved by TAEIG for transmittal to the FAA at our April 14, 2010 meeting.

The Working Group strongly recommends that all of the recommendations be implemented as a “package” in order to achieve the benefit of the proposed revisions and that the changes are intended to be applied to new TC or STC projects and not retroactively. There are also several recommendations from the Working Group for follow-on activity that was beyond the scope of this task.

I would like to express my thanks to the entire working Group and the co-chairs for the extraordinary work that was done on this very difficult and challenging task.

Sincerely yours,

Craig R. Bolt

C. R. Bolt
Assistant Chair, TAEIG

Copy: Mike Kaszycki – FAA-NWR
Roger Knepper – Airbus
Ed Wineman - Gulfstream
James Wilborn – FAA-NWR
Suzanne Masterson – FAA NWR
Ralen Gao – FAA-Washington, D.C. – Office of Rulemaking

U.S. Department
of Transportation
**Federal Aviation
Administration**

800 Independence Ave., SW.
Washington, DC 20591

Mr. Craig R. Bolt
Assistant Chair, Aviation Rulemaking
Advisory Committee
Pratt & Whitney
400 Main Street, Mail Stop 162-14
East Hartford, CT 06108

Dear Mr. Bolt:

This is in reply to your May 11, 2010 letter. Your letter transmitted to the FAA the Aviation Rulemaking Advisory Committee's (ARAC) recommendations regarding specific risk assessments in the areas of Latent failures, Aging & Wear, MMEL and Flight and Diversion Time. I understand that members of the Airplane-Level Safety Analysis Working Group (ASAWG) reached consensus in the areas of Aging & Wear and MMEL, whereas the Working Group documented dissenting opinions regarding recommendations concerning Latent failures and Flight and Diversion Time, and that the Transport Airplane and Engine Issues Group (TAEIG) unanimously approved the final report.

I wish to thank the ARAC, particularly the members associated with TAEIG and its ASAWG that provided resources to develop the report and recommendation. The report will be placed on the ARAC website at: http://www.faa.gov/regulations_policies/rulemaking/committees/arac/.

We consider your submittal of the ASAWG report as completion of tasking from our March 21, 2006 tasking statement (71 FR 14284). We will keep the committee apprised of the agency's efforts on this recommendation through the FAA report at future ARAC meetings.

Sincerely,

Pamela Hamilton-Powell
Director, Office of Rulemaking

ARAC ASAWG Report

Specific Risk Tasking

(Rev. 5.0)

April 2010

Ed Wineman ASAWG Co-chair	Roger Knepper ASAWG Co-chair

REVISION SHEET

Rev	**Description Summary**	**Date**
1.0	Basic Release	Nov 2006
2.5	Updated with comments included up to Web Meeting #5	May 2007
2.7	Comments provided up to Meeting #4 (Merignac) - Included Fig 6-1 (Design risk). - “Increase” wording was excluded from SR definition. - SRC (Specific Risk of Concern) definition was introduced along with the revision of Fig 6-2 (Task 3 entry flow diagram). - It was identified additional conditions for further considerations (Operating Mode, Flight Condition, Flight Phase, and At Risk Time), based on the review of SR definition.	Jun 2007
	Addressed Rev 2.7 comments provided by: Rod L., Alain C, Christophe G, Roger K, David M, Jim M, Linh L, Mike M, Nelson W, Ramesh N and Jim M.	Jul 2007
	Incorporate comments discussed during WM6, WM7 and WM8.	Aug 2007
3.0X	Version of the report reviewed by members for closure of the Task 1 and Task 2. Cleaned up version sent out for TAEIG review	Oct 2007
3.0	Task 3 report version (Seattle Meeting)	Apr 2008
4.0	Task 4 report version	Sep 2009
5.0	Final report version	Apr 2010

TABLE OF CONTENT

Contributing organizations and individuals

Name	Company	Member Status
Knepper, Roger	*Airbus*	*ASAWG (Co-chair)*
Lalley, Rod	*Airbus*	*SME*
Sek, Joachim	*Airbus*	*SME*
Vigarios, Philippe	*Airbus*	*SME*
Haraguchi, Nelshio	*ANAC*	*ASAWG*
Biasotto, Eduardo	*ANAC*	*SME*
Wilmers, Nelson	*ANAC*	*SME*
Merdgen, David	*Boeing*	*ASAWG (Flight Sub Team Chair)*
Schultz, Larry	*Boeing*	*SME*
Tritz, Terry	*Boeing*	*SME*
Nordstrom, Paul	*Boeing*	*SME*
Robertson, CW	*Cessna*	*ASAWG (Design Sub Team Chair)*
Montgomery, Scott	*Cessna*	*SME*
Giraudeau, Christophe	*Dassault Aviation*	*ASAWG (MMEL Sub Team Chair)*
Cabasson, Alain	*Dassault Aviation*	*SME (Latent Sub Team Co-Chair)*
Robinson, Steve	*Hawker Beechcraft*	*SME*
Michael, Branch	*Honeywell*	*ASAWG*
Mattei, Patrick	*EASA*	*ASAWG*
Polano, Nadine	*EASA*	*SME*

Name	Company	Member Status
Hancock, Colin	*EASA-Flight Standards*	*SME*
Paik, Ji	*Embraer*	*ASAWG (Report Issuer)*
Azevedo, Ann	*FAA – CSTA*	*O/A*
Lambregt, Tony	*FAA – CSTA*	*O/A*
Larsen, Hals	*FAA – CSTA*	*O/A*
Sheppard, James	*FAA - AEG SEA*	*SME*
Grant, Bob	*FAA - E&PD*	*SME*
Le, Linh	*FAA – TAD*	*ASAWG*
Martin, Todd	*FAA – TAD*	*SME*
McRae, Mike	*FAA - TAD*	*SME*
Narine, Rameshwar	*Garmin*	*SME*
Mingler, Paul	*GE*	*ASAWG*
Wineman, Ed	*Gulfstream*	*ASAWG (Co-chair)*
Bartron, Michael	*Pratt & Whitney*	*ASAWG*
Peterson, Michael	*Rockwell Collins*	*ASAWG (Latent Sub Team Co-Chair)*
Prasuhn, Warren	*Rockwell Collins*	*SME*
Peacock, Rebecca	*Rolls Royce*	*ASAWG*
Marko, Jim	*TCCA*	*ASAWG*

1 Executive Summary

This tasking is to direct the Aviation Rulemaking Advisory Committee (ARAC) to provide information about specific risk assessment and make recommendations for revising requirements or guidance material as appropriate.

An "Airplane-level Safety Analysis Working Group" (ASAWG) was asked to perform the following tasks:

- Task 1: Develop definition of specific risk and catalog examples of its application.
- Task 2: Identify relevant requirements, guidance and recommendations related to specific risk and its use.
- Task 3: Determine adequacy of the existing/proposed standards and if a change is warranted.
- Task 4: Develop recommendations for rulemaking and guidance material.

Tasking boundaries are:

- Issues outside the flight envelope or outside design specifications are not addressed,
- Methodologies not covering airplane certification but currently being employed to handle conditions such as manufacturing defects, quality escapes, etc. (i.e. Gunstone / CAAM) are not addressed,
- Specific risks, if they lead to a failure condition of Major or less severe criticality, are not addressed,
- Specific risks associated with airframe structures are not addressed.

Task 1 defined Specific Risk in general terms as "The risk on a given flight due to a particular condition". The Specific Risks of Concern (SRC) are when the airplane is one failure away from a catastrophe, or when the risk is greater than the average probability criteria provided in AC 25.1309 Arsenal for hazardous and catastrophic failure conditions, on a given flight due to a particular condition.

Examples of regulations, guidance and industry practices provided the correct and concise understanding of the specific risk definition.

The particular conditions identified for detailed considerations were:

- Latent Failure,

- MMEL,
- Active Failure / Design Variability / Flight Condition / Operating Mode,
- Flight Time / Diversion Time / Flight Phase / At Risk Time.

The ASAWG reviewed during Task 2 the background and intent of relevant existing requirements, existing guidance material, and ARAC recommendations and explained how specific risk is addressed.

The ASAWG reviewed during Task 3 the results of Tasks 1 & 2 and determined the appropriateness, adequacy, and consistency of the relevant existing regulations, existing guidance material, ARAC recommendations, and industry practices for airplane-level safety analysis. The key approaches to addressing Specific Risk were identified as "fundamental issues". For each fundamental issue recommendations for Task 4 were developed:

- Conducting specific risk evaluations of latent and active failures.
- Conducting specific risk evaluation for dispatch under a MEL.
- FHA development when dealing with intensifying factors such as flight length, flight phase and diversions.
- Documenting component replacement times that are necessary to protect against aging and wear out.

These recommendations demonstrate where a more consistent approach across systems is necessary to:

- Assure a warranted level of specific risk regulation, i.e. inconsistency potentially results in over- or under-regulation, and
- Avoid undue burden on the applicant and regulatory authorities.

In accordance with the Task 3 outcome, the ASAWG established Task 4 change recommendations for existing regulations, existing guidance material, ARAC recommendations, and industry practices for airplane-level safety analysis. The change recommendations were reviewed with comments and dissenting opinions generated. All dissenting opinions were either reviewed by the entire ASAWG or by the responsible Sub-Group Chair with dispositions developed. These responses were then transmitted back out to the entire ASAWG for one final review.

The ASAWG concluded on change recommendations for Latent failures, Aging & Wear, MMEL and Flight & Diversion Time Task. Along with the change recommendations benefits, applicability, rationales, alternatives considered (if any) and dissenting opinions (if any) are provided. These changes will apply to new TC or STC and will not be applied retroactively, unless requested by the applicant.

The change recommendations for Latent failures are related to changing both regulations and guidance material. This is the only change recommendation the ASAWG is recommending to regulations.

ASAWG has made tradeoffs between invalidating existing designs, increasing the analytical burden and being conservative when deriving the recommended airplane level specific risk criteria. The key benefit Industry saw after several years of review and discussion was harmonization and consistency across all systems and between various regulation bodies. Unlike previous working groups that were tasked to respond to a specific event or threat that had occurred, this effort is more of a harmonization across the aircraft and regulatory bodies. Therefore, the identification of potential measurable safety benefits was not identified.

The Latent failure change recommendation:

- Eliminates the inconsistent application of various residual risk criteria via IPs and CRIs ranging from 1E-3 to 1E-6. Manufacturers and Regulators alike spend excessive time early in the airplane development cycle negotiating these based on their specific airplane and system designs. The cost related to this was impractical for the manufacturers and regulators to quantify but involve both non-recurring labor cost and recurring equipment costs.
- Increases safety by providing applicants and regulators clear guidance that can be applied consistently across systems,
- Avoids non-standardized system safety assessments across various critical systems making it hard to properly evaluate at the aircraft level, which could cause conflicting interpretations for conducting system safety assessments in aircraft certification programs. Currently, manufacturers performing aircraft level analysis or highly integrated system level analysis based on the worst case criteria. This has the potential to add cost and complexity to the systems. The actual value of this savings could not be quantified when looking at existing systems.
- Provides for an acceptable level of safety across all systems and applications. This is intended to be adequate for coverage of all systems related to specific risk and minimize the generation of new rules, special conditions, IPs, CRIs, etc. in the future.

The change recommendations for Aging & Wear, MMEL Task and Flight & Diversion Time are related to guidance material. Recommendations to change regulations were not seen as appropriate and necessary.

The Ageing & Wear change recommendation increases safety by providing applicants and regulators clear guidance that can be applied across systems to ensure consistent documentation of system component replacement times that are necessary to protect against aging and wear out.

The MMEL change recommendation provides numerical analysis guidance which would provide a standardized methodology that would maintain fleet average reliability objectives when used to support a proposed MMEL item's qualitative assessment.

The Flight & Diversion Time change recommendation increases safety through elimination of errors in the application of the guidance and by providing applicants and regulators clear guidance that can be applied consistently across systems:

- Treat flight time, flight phase and diversion time in the FHA in same manner across applicants and across systems from a single applicant.
- Ensure correct hazard classification in FHAs take into account intensifying factors, such that specific risk concerns worthy of being addressed are not overlooked.
- Eliminate confusion with respect to the compounding nature of factors in defining the hazard classifications in an FHA.
- Eliminate the misunderstandings due to unclear guidance on how environmental or operational factors are combined with single failures.
- Harmonized use of average long-range flight duration and maximum diversion time for both type 1 and type 2 systems in compliance to the new ETOPS rule.

2 Purpose / Background

The FAA established the Aviation Rulemaking Advisory Committee (ARAC) to provide advice and recommendations to the FAA Administrator on the FAA's rulemaking activities for aviation-related issues. Previous ARAC harmonization working groups (Flight Controls, Power Plant Installations, and Systems Design and Analysis) produced varying recommendations regarding the safety of critical airplane systems. Although the subject of specific risk analysis was addressed in those working groups, the recommendations were not consistent. Regulations and Policies developed from within the FAA also provide approaches different from those recommended by ARAC.

If these different approaches are applied on a typical certification project, they could result in non-standardized system safety assessments across various critical systems. This could cause conflicting interpretations for conducting system safety assessments in future aircraft certification programs. After reviewing the existing regulations and the recommendations from the various harmonization-working groups, the FAA Transport Airplane Directorate, along with the European, Canadian, and Brazilian civil aviation authorities, identified a need to clarify and standardize safety assessment criteria. The FAA decided to use a new ARAC tasking to integrate the safety assessment criteria from various system disciplines. In July 2005, an industry group comprised of the Aerospace Industries Association (AIA), General Aviation Manufacturers Association (GAMA), and several aircraft and engine manufacturers, proposed a new tasking. The FAA agreed with the industry group proposal, and has based this tasking on that proposal.

3 Scope

This tasking is to direct ARAC to provide information about specific risk assessment and make recommendations for revising requirements or guidance material as appropriate. An “Airplane-level Safety Analysis Working Group” (ASAWG) is to perform the following tasks:

Task 1: The ASAWG is to establish a definition for specific risk. It is to provide relevant examples of its application in today’s aircraft certification, FAA Flight Operations Evaluation Board (FOEB), and Maintenance Review Board (MRB) activities.

Task 2: The ASAWG is to review the background and intent of relevant existing requirements, existing guidance material, and ARAC recommendations and explain how specific risk is addressed. In Task 2, the ASAWG is to document all current and proposed approaches to specific risk but should not establish how specific risk should be assessed.

Task 3: The ASAWG is to review the results of Tasks 1 & 2 and determine the appropriateness and adequacy of existing and proposed airworthiness standards for airplane-level safety analysis. This task is to demonstrate if a more consistent approach across systems is necessary. Concurrence from the TAE Issues Group and the FAA is required before continuing to Task 4.

Task 4: The ASAWG is to develop a report containing recommendations for rulemaking or guidance material and explain the rationale and safety benefits for each proposed change. The report is to define a standardized approach for applying specific risk in the appropriate circumstances. The FAA is to define the report format to ensure the report contains the necessary information for developing a Notice of Proposed Rulemaking (NPRM), and/or ACs.

Unlike the tasking statements above, following boundaries were not defined within the tasking, but rather derived by the ARAC ASAWG and agreed by ARAC TAEIG to further bound the tasking. These boundaries are the ARAC Specific Risk tasking should not address issues outside the flight envelope nor outside design specifications. Methodologies currently being employed to handle conditions such as manufacturing defects, quality escapes, etc. (i.e. Gunstone / CAAM) are not covered under Certification of the airplane; therefore, they are also beyond the scope of the ARAC tasking. The ARAC Specific Risk Tasking should not address specific risks, if they lead to a failure condition of Major or less severe criticality.

In addition, specific risk associated with airframe structures should not be addressed by this Tasking. Many of the transport category airplane airworthiness rules, policies and practices used to establish a minimum acceptable level of safety for airframe structure involve regulating what we have defined as a “specific risk”. These rules, policies and practices are often intended to prevent the occurrence of a particular failure (e.g. fracture of a primary structural element) given below average parts (e.g. those with maximum undetectable flaws and/or likely damage) are exposed to above average stresses (e.g. limit and/or ultimate loads). However, as indicated by the following statement from Task 3: *"This task is to demonstrate if a more consistent approach across systems is necessary"*; this overall tasking is focused on "systems" related rules, policies and practices. Consequently, while structural examples may ultimately provide some valuable insights as to how failure prevention might be undertaken for a particular critical part within airplane systems, such examples were not included in Task 2.

Note: This document contains a vast amount of "historical" information generated in the process of reaching the set of recommendations coming out of the tasks. This information is contained in the form of Word tables and Excel workbooks. Due to the size of this information, these files are embedded within the text of this document. Therefore, each of these tables will need to be printed individually if the reader wants a hard copy of this data.

4 Abbreviations

AC	Advisory Circular
AD	Airworthiness Directive
AEG	Aircraft Evaluation Groups
AFM	Aircraft Flight Manual
AIA	Aerospace Industries Association
ANAC	Agência Nacional de Aviação Civil
ARAC	Rulemaking Advisory Committee
ASAWG	Airplane-level Safety Analysis Working Group
CAAM	Continued Airworthiness Assessment Methodology
CFR	Code of Federal Regulations
CMR	Certification Maintenance Requirement
CS (JAR)	Certification Standard (Joint Aviation Requirements)
CSTA	Chief Scientist Technical Advisor
E&PD	Engine and Propeller Directorate
EASA	European Aviation Safety Agency
EPRD	Electronic Part Reliability Data
ETOPS	Extended Range Operation
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
FH	Flight Hour
FHA	Functional Hazard Assessment
FMEA	Failure Mode Effect Analysis
FOEB	Flight Operations Evaluation Board
GAMA	General Aviation Manufacturers Association
HIRF/IEL	High Intensity Radio Frequency
IAW	In Accordance With
JOEB	Joint Operations Evaluation Board
LRU	Line Replaceable Unit
MMEL	Master Minimum Equipment List
MIL HDBK	Military Handbook

MOC	Means of Compliance
MRB	Maintenance Review Board
MTBF	Mean Time Between Failure
NPRD	Non Electronic Part Reliability Data
NPRM	Notice of Proposed Rulemaking
OEM	Original Equipment Manufacturer’s
PSE	Primary Structural Element
SME	Subject Matter Expert
SR	Specific Risk
SRC	Specific Risk of Concern
SSA	System Safety Assessment
STC	Supplemental Type Certification
TAD	Transport Aircraft Directorate
TAEIG	Transport Airplane Engine Issues Group
TBD	To Be Defined
TCCA	Transport Canada Civil Aviation

5 Bibliography

ARP 4761	
AC 25.1309	
Gunstone	
CAAM	

6 Development

6.1 Task 1

6.1.1 Introduction

The ASAWG had to establish during Task 1 a definition for specific risk and provide relevant examples of its application.

Firstly, available specific risk definitions were reviewed and specific risk related regulations, guidance and industry practices were discussed. Then a specific risk and specific risk of concern definitions have been established by the ASAWG. Further on potential relevant conditions for specific risk were identified. These conditions were guided by the ARAC tasking notice. It identifies potential relevant conditions for specific risk as follows: Latent failure, MMEL, Airplane configurations, and Flight conditions.

The specific risk definition was applied to each condition and vice versa with the support of key questions. These questions were crucial for the scope of the ARAC Tasking such as compliance with average probability criteria of 25.1309 Arsenal. This application identified how relevant these conditions were, given the specific risk definition, and whether they would have to be addressed further under ARAC Specific Risk Task 3.

Examples of regulations, guidance and industry practices helped for the correct and concise understanding of the specific risk definition.

6.1.2 SR & SRC definitions

The ARAC Tasking notice required the development of a definition for Specific Risk that considered the certification aspects, operational aspects and maintenance aspects used in today's aircraft design development and certification processes.

The definition for Specific Risk is: ***"The risk on a given flight due to a particular condition".*** The **Specific Risks of Concern (SRC)** are when the airplane is one failure away from a catastrophe, or when the risk is greater than the average probability criteria provided in AC/AMJ 25.1309 Arsenal for hazardous and catastrophic failure conditions, on a given flight due to a particular condition.

6.1.2.1 History

In order to develop the definition for specific risk that was thorough yet concise a complete understanding of what went before had to be understood by the ASAWG members.

The genesis of Specific Risk tasking date's back to 1993 with a FAA statement of work to ARAC to develop guidance for specific risk bridging the requirements of 14CFR 25.901(c), 14CFR 25.1309 and MMEL development. The ARAC Working Group (WG) could not close its deliberations by 1998 and recommended guidance in the form of a draft AC (Diamond version of AC/AMJ 25.1309) that supported average risk assessment methodology. In 2001, the FAA proposed revisions to the 1998 ARAC recommendations to cover specific risk. This guidance was introduced into a preliminary Draft AC 25.1309-1BX which lead to draft arsenal version of AC/AMJ 25.1309.

Meanwhile the Diamond version developed in 1998 by the ARAC WG was adopted by the European community and was included with EASA's CS 25.1309 in October of 2003. Also during this time, guidance and policy was being recommended and/or released in the areas of thrust reversers (FAR25.933 and AC 25.933X), fuel tank ignition (SFAR 88, FAR25.981 and AC25.981-1B), powerplant installations (FAR25.901(c) policy), flight controls (FAR25.671) and MMEL policy prohibiting dispatch in catastrophic single-failure conditions.

In the end, it had become apparent that the various approaches were inconsistent when viewed together at the airplane level. In addition, there was no stated common definition or general understanding of "Specific Risk".

6.1.2.2 Rationale

The basic precepts provided to the ASAWG when developing the definition for Specific Risk was it must be thorough yet concise. The definition should not invalidate previous work. The definition should not encompass methodology nor describe how specific risk should be addressed. The goal was to encompass the definition into a single sentence. Finally, the definition had to stand up to a review process that ensured the basic precepts were maintained.

To discuss specific risk at the aircraft level, it was decided to compare it to the quantitative average probability criteria as defined by AC/AMJ 25.1309 Arsenal. The term "Average Risk" is understood to represent the average probability of failure for some baseline population of airplanes over their entire life. Specific risk may be above, below or equal to this average. However, it was recognized that any Specific Risk of Concern must increase the risk relative to the average probability criteria as defined by AC/AMJ 25.1309 Arsenal.

Figure 6-1 illustrates the relationship between the specific risks of concern and the average probability criteria of AC/AMJ 25.1309 arsenal. The Specific Risk of Concern (SRC) depicted represent deviation that can occur on specific flights.

A basic assumption was the baseline population would be defined as any aircraft configuration used in the average risk calculation. Aircraft that encompass additional Supplemental Type Certifications (STCs) and/or production options that constitute a different configuration would then just be considered a new population and not a subset of the baseline configuration. Thus, the definition above was developed.

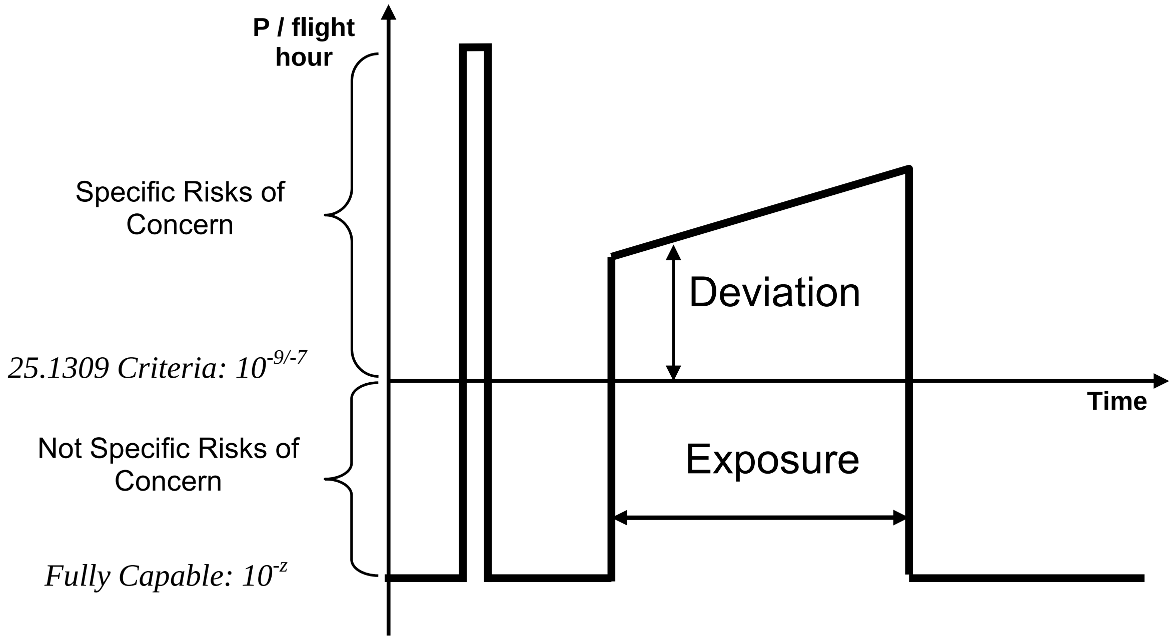


Figure 6-1: Design Risk for a Failure Condition

6.1.3 Application of the Definition

Specific Risk is the risk on a given flight due to a particular condition. Of interest are the **Specific Risks of Concern (SRC)** when the airplane is one failure away from a catastrophe, or when the risk is greater than the average probability criteria provided in AC/AMJ 25.1309 Arsenal for hazardous and catastrophic failure conditions, on a given flight due to a particular condition. Therefore, this leaves the process related to the identification of the particular conditions as being critical to the definition.

6.1.3.1 Particular Condition Development

The identification of the conditions potentially relevant to specific risk was guided by the ARAC tasking notice. Latent Failures and MMEL relief was immediately recognized as relevant. Various airplane configurations and flight conditions were also identified as potentially relevant conditions. Environmental or operating conditions that were outside the flight envelope and/or design specification of the baseline aircraft were ground ruled out as particular conditions that would be identified and reviewed by the ASAWG for specific risk conditions. Some of these include flight into volcanic ash, flight into icing in excess of the conditions defined in Appendix C of 14CFR25, etc.

Various airplane configurations and flight conditions were further broken down into subsets to include such items as operating modes, active failure conditions, design variability, flight phase, flight time, diversions / return to land conditions and flight conditions. Design variability included design characteristics such as aging and wear that may impact the assumption of a component operating under a random failure distribution condition for the life of the aircraft, but design variability did not include such items as aircraft reconfigurations due to application of an STC to a given aircraft. As stated earlier, an STC aircraft is considered to be a new baseline. Active failure modes were separated from operating modes by recognizing the difference of operating the aircraft under emergency or abnormal operating procedures of the Aircraft Flight Manual (AFM) vs. the normal operating procedures. The distinction between the two is that one mode is entered because of an equipment malfunction while the other is selected by the pilot.

These conditions were then categorized as "Actual" or "Potential". The "Actual Conditions" were defined as those conditions that are identifiable for a specific airplane or flight prior to the initiation of the flight. The "Potential Conditions" were defined as those conditions that are not known to exist for a specific airplane or flight but may be expected to exist prior to the initiation of some flights during the fleet life.

6.1.3.2 Task 3 Relevancy Logic

To determine if a particular condition was a specific risk of concern and was worthy to proceed to Task 3, the ASAWG membership developed a series of decision points to go through. A simple logic diagram is provided in Figure 6-2 that illustrates the decisions that should be passed through to determine if the particular condition is considered Task 3 relevant or not. Only one particular condition at a time goes through the decision points.

The first decision point is simply a determination if the particular condition is considered inside or outside of the design envelope (i.e. design specification) and certification basis of the aircraft. If the condition is outside the design conditions of the aircraft then it is not considered within the boundaries as established for the ARAC Specific Risk tasking.

The remaining decision points in the diagram are an attempt to determine the level of increased risk introduced by each particular condition, with its specific assumptions made for these conditions as identified in 6.1.3.3. This assumption was only applied during Task 1 for the identification of particular conditions to be considered relevant for Task 3.

At this point in the flow diagram, the aircraft configuration does not change from one decision to the next, nor can the particular condition under review be changed. The first decision, determines if the particular condition can leave the aircraft one failure away from a catastrophe. If the answer is no then the next decision point, must be passed for determination if the assumed particular condition has a remaining risk greater than the average probability criteria (i.e. 1E-7/1E-9/FH) of AC/AMJ 25.1309 Arsenal.

To better understand the intent of the third decision point, Figure 6-1 above can be reviewed. When the airplane operates in the full-up configuration (i.e. no failures) the risk of a failure condition is by regulation below the design criteria called out in AC/AMJ 25.1309 Arsenal. The criterion of the third decision looks at what configuration the aircraft may be in when a particular condition is evaluated.

At this point, the particular condition becomes the variable and it is the only variable that changes when it is applied to the aircraft design characteristics to see if the minimum probability criterion of AC/AMJ 25.1309 Arsenal has been exceeded. If the answer is no then this is not a specific risk of concern otherwise the condition is to proceed for review in Task 3. Though the particular condition may satisfy the no decision criteria the applicable requirements and/or guidance could still be reviewed in Task 3. The results of these assessments are to be reported to TAEIG Issues Group prior to initiation of Task 4.

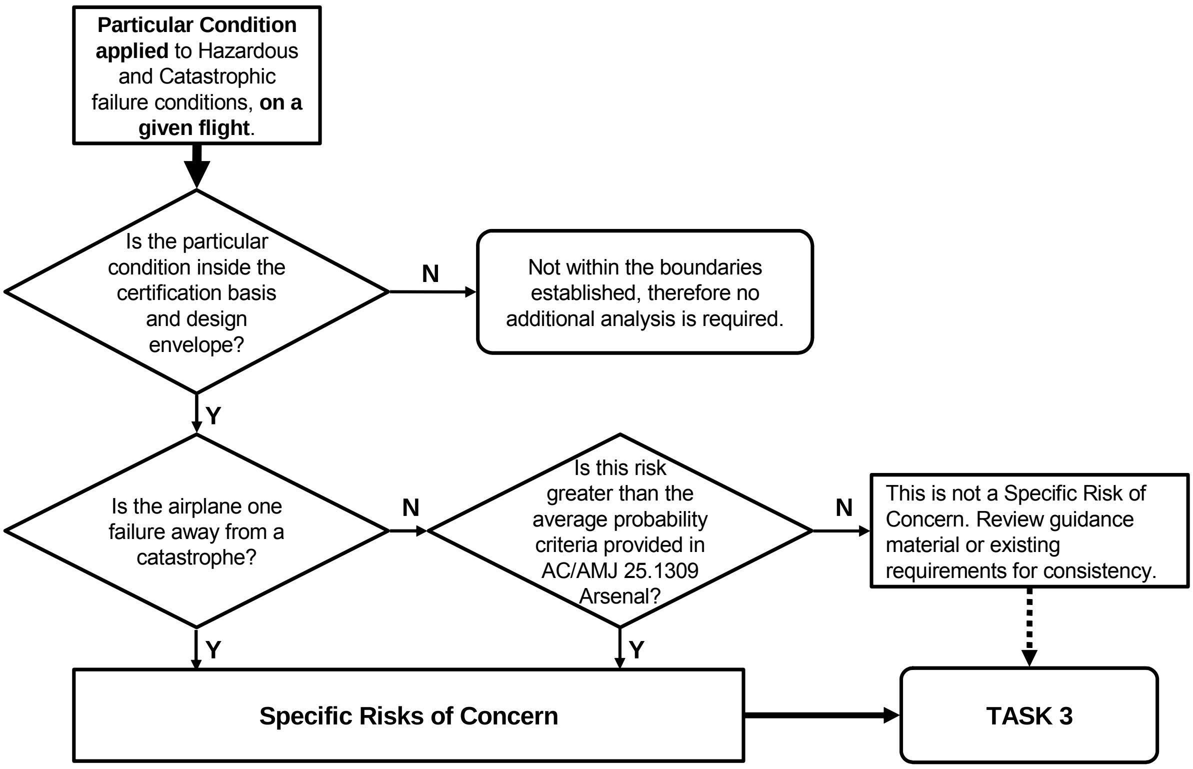


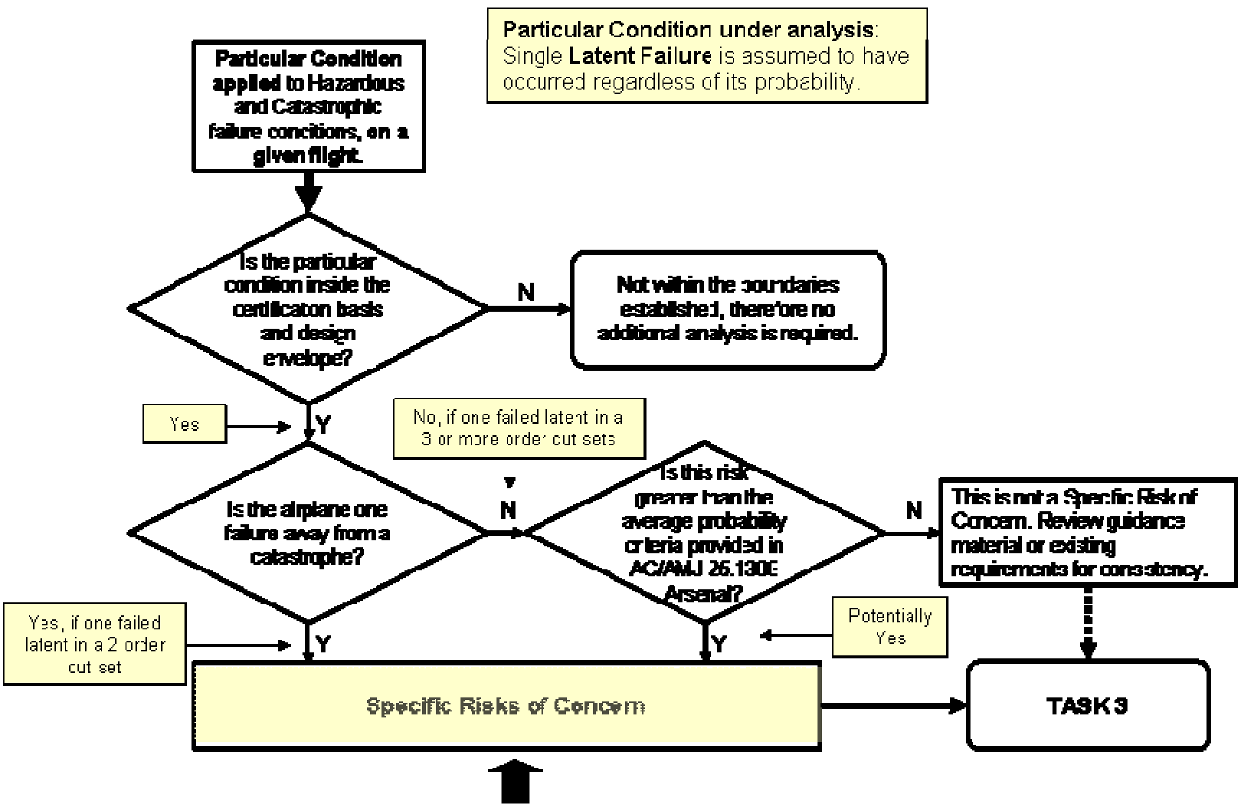
Figure 6-2: Task 3 Entry Flow Diagram

6.1.3.3 Decision (SRC, non SRC)

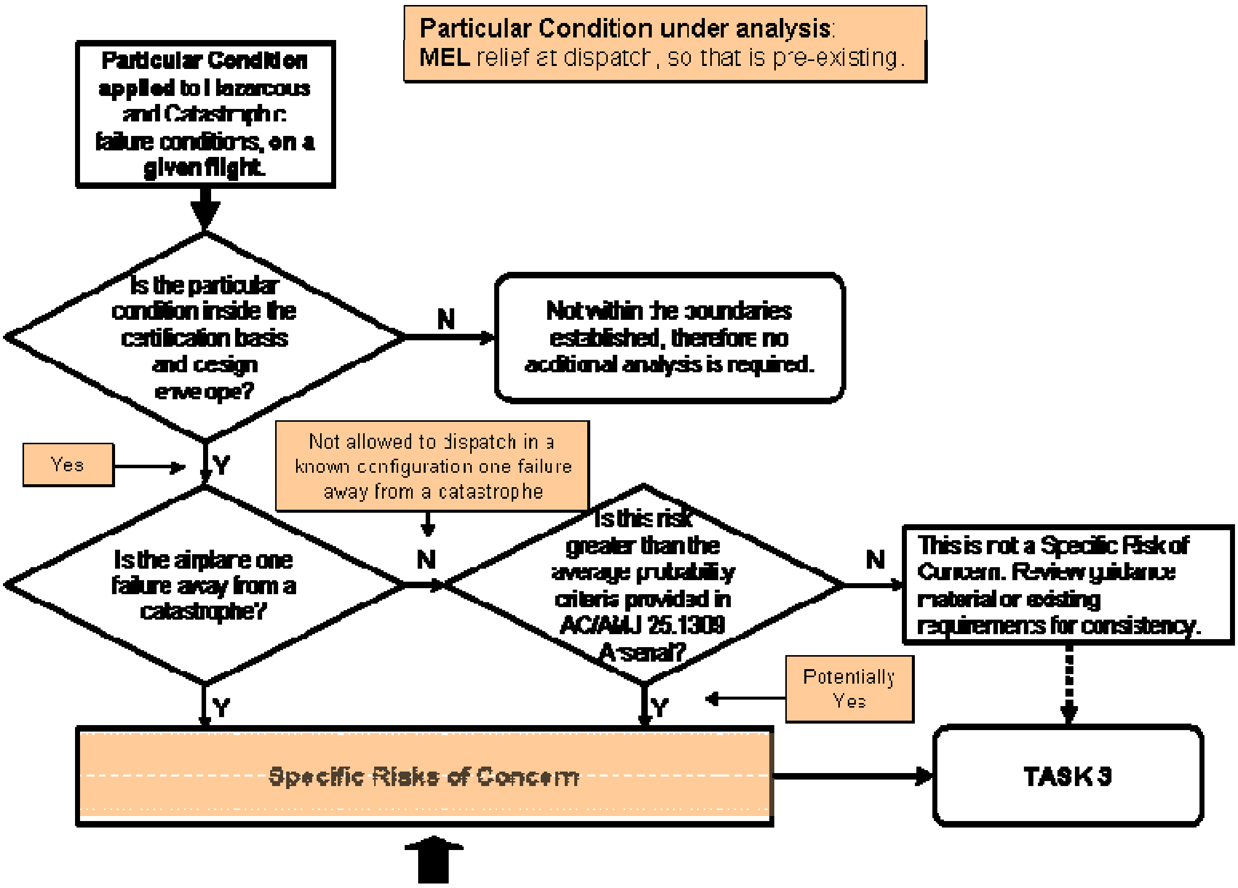
To apply the definition for specific risk developed by the ASAWG to a particular condition, the logic diagram described above was used for various conditions that historically had been agreed to be specific risk conditions. These two were latent failures and MMEL dispatch conditions. Additional conditions as defined in 6.1.3.1 were also tested. The following Table 6-1 provides the results of this testing process while the figures provide a graphic step by step view of the logic taken when progressing through the flow chart in Figure 6-2.

Examples from each sub-task are provided using the flow diagram of Figure 6-2 and applying to some particular conditions:

- Latent Failure

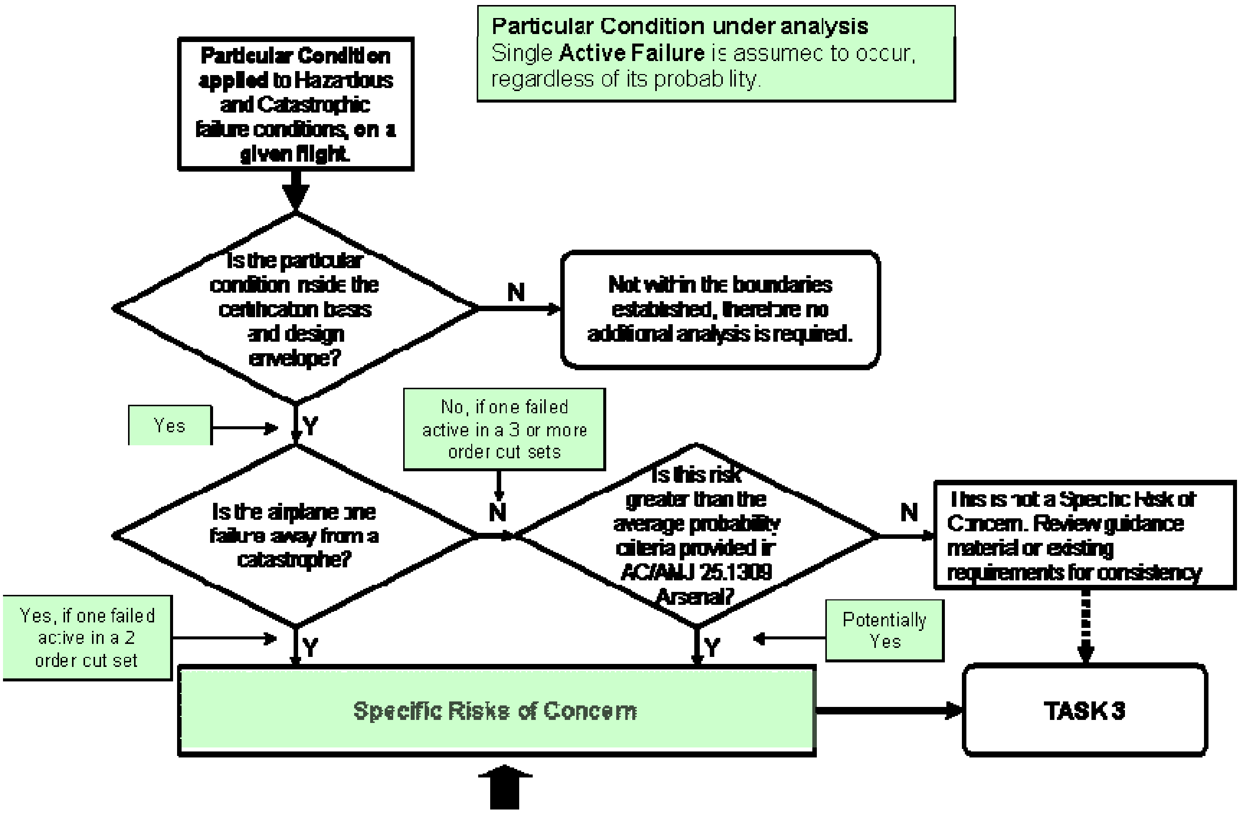


- MMEL

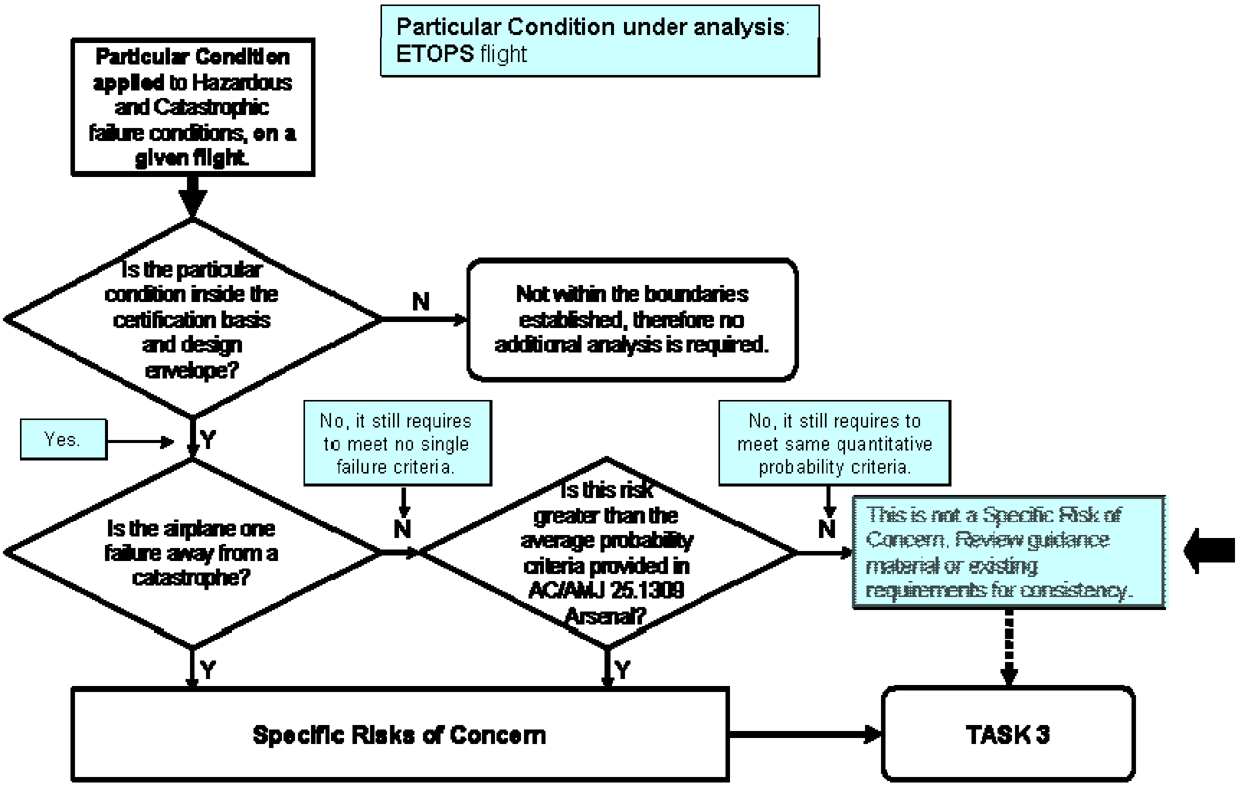


Particular Condition under analysis:
MEL relief at dispatch, so that is pre-existing.
Particular Condition applied to Hazardous and Catastrophic failure conditions, on a given flight.
Is the particular condition inside the certification basis and design envelope?
N
Not within the boundaries established, therefore no additional analysis is required.
Yes
Y
Not allowed to dispatch in a known configuration one failure away from a catastrophe
Is the airplane one failure away from a catastrophe?
N
Is this risk greater than the average probability criteria provided in AC/AMJ 25.1309 Arsenal?
N
This is not a Specific Risk of Concern. Review guidance material or existing requirements for consistency.
Potentially Yes
Y
Y
Specific Risks of Concern
TASK 3

- Active Failure



- Flight Time



The particular conditions tested and a brief description or examples of the type of conditions were:

- **Latent Failure** – A failure is latent until it is made known to the flight crew or maintenance personnel.
- **MMEL** – Recognized or approved under FAR 91 configurations of the aircraft that are permitted at dispatch using operating rules, but may leave the aircraft in a configuration that is less than that evaluated for certification under FAR/CS 25.
- **Operating Modes** – These are system or aircraft normal modes (abnormal modes are addressed in other particular conditions, e.g. active failures) such as auto pilot on/off, flaps up/down, etc…, that the pilot places the aircraft in.
- **Flight Condition** – This include most of the environmental conditions such as flight over water or high terrain, high altitude operations, operating into high cross winds or extreme cold environments, etc.
- **Design Variability** - Includes design characteristics such as aging, wear, cycle dependencies that may impact the assumption a component was operating under a random failure distribution condition for the life of the aircraft, but it did not include

such items as aircraft reconfigurations such as application of a specific STC on a given aircraft

- **Active Failure**– Equipment / system failure conditions which are identifiable during the flight for a specific airplane.
- **Flight Time** – Encompasses all the permitted flight that goes into the calculation of average flight time. It recognizes the potential for one aircraft to be operating in a very high cycle condition but low average flight time to the extreme of ultra long flights that include ETOPS operations.
- **Diversion / Return to Land Conditions** – The conditions associated with an in-flight emergency being that requires the crew to proceed to the closest landing site. This could be caused by a medical condition of a passenger or other external event such as a bird strike at takeoff or other.
- **Flight Phase** – Includes the classic conditions such as taxi, takeoff, climb, cruise, descent and landing. Each condition covers the entire average time associated with that condition.
- **At Risk Time** – The period of time at which an item must fail in order to cause the failure effect in question. This is usually associated with the final fault in a fault sequence leading to a specific failure condition.

The particular conditions were categorized as either potential risk conditions or actual risk conditions as defined in section 6.1.3.1 above.

The results of the testing identified ten potential condition categories that the ASAWG had to be investigating during Task 2 and 3. Some examples of these types of conditions and a more thorough explanation of the types of conditions included in these categories are provided in the follow on sections. The conditions identified for further considerations were:

- Latent Failure
- MMEL
- Active Failure
- Operating Mode
- Flight Condition
- Design Variability
- Flight Time
- Diversion / Return to Land
- Flight Phase
- At Risk Time

The Specific Risk is the risk on a given flight due to a particular condition. *The* ***Specific Risks of Concern (SRC)*** *are when the airplane is one failure away from a catastrophe, or when the risk is greater than the average probability criteria provided in AC/AMJ 25.1309 Arsenal for hazardous and catastrophic failure conditions, on a given flight due to a particular condition.*					
Particular Condition applied to Haz / Cat FC on a given flight.	Inside Envelope / Spec?	Actual or Potential risk condition?	Is the airplane one failure away from a catastrophe?	Is the risk greater than the average probability criteria provided in AC/AMJ 25.1309 Arsenal?	Comments
MMEL	Y	A	N	Y	- Acceptable level of safety to be defined (JAR MMEL). - Standardized approach to be developed. - Some OEMs satisfy average probability criteria of AC/AMJ 25.1309 Arsenal.
Operating mode	Y	A	N	Y	- Some operating modes inside the envelope are assumed to have a probability of 1 (average probability criteria of AC/AMJ 25.1309 Arsenal not exceeded). There may be other conditions that have probabilities less than 1 (average probability criteria of AC/AMJ 25.1309 Arsenal potentially exceeded, if probability of 1 would be assumed). - Operating modes related to failures are addressed separately. - This is not SRC in and of itself.
Flight condition	Y	A	Y	Y	- Some flight conditions inside the envelope are assumed to have a probability of 1 (average probability criteria of AC/AMJ 25.1309 Arsenal not exceeded). There may be other conditions that have probabilities less than 1 (average probability criteria of AC/AMJ 25.1309 Arsenal potentially exceeded, if probability of 1 would be assumed). Examples may be crosswind, gust and turbulence. - Not SRC in and of itself.
Design variability	Y/N	A	N	Y/N	- Variability affects a random failure distribution.
Flight phase	Y	A	N	Y	- Average probability criteria of AC/AMJ 25.1309 Arsenal potentially exceeded, if an occurrence probability especially for this flight phase calculated, i.e. without normalizing using the average flight time hour.
Flight time	Y	A	N	Y/N	- If flight time is always below average, than cycling effects are perhaps not properly covered. - 25.1309 compliance: ETOPS assessments to meet 25.1309 criteria per Part 25 Appendix K. Other SSAs use fleet average flight times which may not be conservative for all cases.

The Specific Risk is the risk on a given flight due to a particular condition. *The **Specific Risks of Concern (SRC)** are when the airplane is one failure away from a catastrophe, or when the risk is greater than the average probability criteria provided in AC/AMJ 25.1309 Arsenal for hazardous and catastrophic failure conditions, on a given flight due to a particular condition.*					
Particular Condition applied to Haz / Cat FC on a given flight.	Inside Envelope / Spec?	Actual or Potential risk condition?	Is the airplane one failure away from a catastrophe?	Is the risk greater than the average probability criteria provided in AC/AMJ 25.1309 Arsenal?	Comments
Diversion / Return to land	Y	P	N	Y	- Issue Paper available.
Latent failure	Y	P	Y	Y	The airplane may be one failure away from catastrophe assuming that one failed latent in a 2 order cut set.
Active failure	Y	P	Y	Y	- The airplane may be one failure away from catastrophe assuming that one failed active in a 2 order cut set,. - Regulations to be re-examined like 25.671, 25.981, 25.933.
At Risk Time	Y	A/P	Y	Y	- Average probability criteria of AC/AMJ 25.1309 Arsenal potentially exceeded, if an occurrence probability especially for this at risk time calculated, i.e. without normalizing using the average flight time hour. - Whether or not it is actual/apparent when a particular airplane is at risk depends upon the particular condition and associated risk under study.

Table 6-1: Specific Risk Analysis Table

6.1.4 SR examples

6.1.4.1 Latent Failure Task

The Latent Failure Task Group was assigned the task to identify and document the current approaches in order to assess in Task 3 the acceptance criteria for the "significant latent failures" highlighted in paragraph 9.c.6 of the proposed ARAC Advisory Circular (AC) 25.1309 - "Draft ARSENAL version," dated 6/10/2002.

In order to provide current examples of latent failure applications, the following items were identified. More details like the background, the intent of relevant existing requirements, the existing guidance material, industry practices, and the explanation of how specific risk is addressed should be reviewed and provided in Task 2.

- AC 33.28-1 (Engine over-speed criteria)
- 25.671
- ARAC 25.671
- Generic IP - 25.933
- ARAC 25.933
- AC 25-19
- AC 25.1309-1A
- AC/AMJ 25.1309 - Arsenal
- ARP 4761 (Maximum dormancy)
- SFAR88 & 25.981
- FAA Policy 25.901(c)
- IP to 25.901(c)

6.1.4.2 MMEL Task

6.1.4.2.1 Background

The FAA MMEL process is an operational process led in the field by Aircraft Evaluation Groups (AEG). FAA HQ Flight Standards division in Washington, DC controls the policy and overall standardization of the MMEL.

The development of standardization and policy guidance is performed by an MMEL FAA/Industry Group (MMEL IG). The MMEL IG is composed of representatives from the FAA, operators and the industry. This group reviews items of equipment that are required by a new regulatory requirement or are MMEL items that are affected by FAA policy decisions. This process has led to the issuance of a set of FAA Policy Letters in which guidance is given to FOEB chairmen for drafting specific MMELs.

FOEB chairmen set up an initial aircraft MMEL based on the aircraft manufacturer's Proposed MMEL (P-MMEL). During a public FOEB meeting that gathers AEG staff and chairman, the respective aircraft manufacturer [OEM] and operators, the initial MMEL is reviewed, and amended as necessary. This updated MMEL is then posted on FAA Opspecs website [draft section] for public comments. After a specified period of time, public comments are reviewed by the FOEB chairman. Final revisions are then made and the MMEL posted in the "Valid" section of the FAA Opspecs website for public use.

This process is further described in Airworthiness Inspector's Handbook, Order 8300.10 - Volume 2 - Chapter 7. This process is also described in FAA Order 8400.10.

6.1.4.2.2 Developing MMEL

In developing their P-MMEL, manufacturers and operators seeking consideration for relief for operating with certain items of equipment inoperative, are requested to provide supporting documentation that sufficiently substantiates their request. In addition to including an evaluation of the potential outcome of operating with specific items inoperative, this documentation should consider the following topics: the subsequent failure of the next most critical component; the interrelationships between items that are inoperative; the specific conditions under which the equipment is to be allowed to be inoperative [provisos]; any necessary Operations and/or Maintenance procedure [M & O's]; the proposed repair interval; the impact on approved flight manual procedures; the reliability of critical components; and any/all potential impacts on crew workload that could adversely degrade safety margins.

The basic concept to be applied in accepting an item for inclusion into a Master Minimum Equipment List is that the subsequent failure of the next most critical component in flight must not lead to a catastrophic event. There are other essential considerations too, however such as qualitative requirements that prohibit the incorporation of items of equipment powered by essential buses, or items of equipment necessary to accomplish an emergency procedure[s]. Related to all of these, is guidance for electrical systems on two-engines airplanes. In addition, the MMEL may not conflict with other FAA-approved documents such as the approved aircraft flight manual limitations, emergency procedures, and/or Airworthiness Directives (AD). AD's always take precedence over any published MMEL relief.

Appropriate restrictions and/or procedures are established to ensure an acceptable level of safety is maintained during the MMEL/MEL deferral period.

Specific OEMs may apply different processes for establishing their Proposed MMEL. These processes range from a full safety analysis established for each item - assigning a probability of one or a conditional probability to the failed item- to a qualitative analysis that is supported by quantitative analysis when requested. These company processes are designed and intended to be more conservative than that required by the FAA.

When an airplane is dispatched under MMEL/MEL relief (i.e. less than full up) it is an example of SRC, as the specific aircraft configuration may now have a risk higher than that established under an average full up configuration.

6.1.4.2.3 Non-US Practices

Transport Canada MMEL process is conducted along with Type certification activities, should end at TC date and involves certification specialist. It is based on safety analyses and it mainly looks at the impact of inoperative item coupled with the next failure and assesses whether the residual probability is still “on the order” of what it should be for the failure classification being assessed.

European process is still processed under JAA rules as EASA has not overtaken this activity. It is driven by JAR-MMEL/MEL, specifically by requirement .010(a) which request "to maintain an acceptable level of safety as intended in the applicable JAR or equivalent Requirement".

6.1.4.3 Airplane Configuration Task

The first task of the group, was to identify and discuss how different Operating Modes of Aircraft Systems, Flight Conditions (Environmental Conditions), Active failure and Design Variability where considered in showing compliance.

All the members that provided feedback on their methods of showing compliance used SAE ARP 4761 (published 1996-12), AMC 25.1309 (2006-5), the Arsenal (2002-6) or Diamond Draft (1998-4) of AC 25.1309. There were slight differences between the companies. This can be attributed to relative newness of the system safety process when compared to mature processes (i.e. structures or pressurization).

As outlined in 25.1309 compliance guidelines mentioned above, the applicant in their functional hazard assessments (FHA), evaluate the effect of the functional failure condition on the aircraft and crew based on the worst case within the certification approved standard, flight envelope and design specification. This sets the hazard classification and drives the qualitative and quantitative requirements, as well as requirements for HIRF/IEL, software and hardware design assurance. While this conservatively takes the severity aspect of the specific risk and treats it as the average, there is still the related issue of the conditional probability of being in the “worst case” condition. As credit for these conditional probabilities is increasingly being taken when showing compliance with the probability guidelines (example: AC25-7A, Appendix 7, HQRM), further consideration of these particular conditions in Task 3 was deemed appropriate, not only to assure the overall specific risk is adequately addressed, but also to assure that the probabilities guidelines associated with less severe outcomes are also met.

6.1.4.4 Flight & Diversion Time Task

The Flight Length and Diversion Time Task Group was assigned the task to identify and document the current approaches to exposure times where specific risk might be applied.

In order to provide current examples of possible Specific Risk application to flight length and diversion time the following examples were reviewed. More details like the background, the intent of relevant existing requirements, the existing guidance material, and the explanation of how specific risk is addressed had to be reviewed and provided in Task 2.

The first task of the group was to identify and discuss how At Risk Time, Flight Phase, Flight Time and Diversion Time were considered in showing compliance.

- "At Risk " Time
  - ARP 4761 Paragraph 2.2 and Appendix D paragraph D.11.1.3.2
  - AC/AMJ 25.1309 (Arsenal) Appendix 3 paragraph b2
- Flight Phase
  - ARP 4761 Appendix A paragraph A.1 and Appendix D paragraph D.11.1.3.2
  - AC/AMJ 25.1309 (Arsenal) Appendix 3 paragraph a and paragraph b2
  - AC 25.1309-1A
  - Draft AC 25.671
  - 25.901c exemption B717 docket no. FAA-2003-14201
  - Industry examples
- Flight Time
  - ARP 4761 paragraph 2.2
  - AC/AMJ 25.1309 (Arsenal) Appendix 3 paragraph c
  - Draft AC 25.671
  - Industry examples
- Diversion Time
  - FAR 121.161
  - ETOPS/JAR-OPS
  - FAA Part 25 Appendix K (new)
  - NPRM Docket No. FAA-2002-6717 Notice No. 03-11
  - AC120-42A Extended Range Operation with Two Engine Airplanes
  - JAR-OPS 1.246 Extended Range Operation with Two Engine Airplanes
  - Return Landing Capability – Generic Issue Paper

The group concluded that At Risk Time, Flight Phase, Flight Time, and Diversion Time are examples of specific risk variables and they should be examined further in Tasks 2 and 3.

6.1.5 ASAWG Recommendation

The ASAWG recommends that "**Specific Risk**" be defined as the "**risk on a given flight due to a particular condition**". In addition, the categories of conditions that should be researched further during Task 2 and 3 should be the following:

- MMEL
- Design Variability
- Flight Time
- Diversion / Return to Land
- Latent Failure
- Active Failure
- Operating Mode
- Flight Condition
- Flight Phase
- At Risk Time

6.2 Task 2

The ASAWG reviewed during Task 2 the background and intent of relevant existing requirements, existing guidance material, and ARAC recommendations and explained how specific risk is addressed. In Task 2, the ASAWG had to document all current and proposed approaches to specific risk but should not establish how specific risk should be assessed. The outcome of this task was a description how specific risk is currently assessed and managed, by currently available regulatory guidance and by actual practice in recent certification programs. Task 2 also included the intended improvements and safety benefits of currently available regulatory guidance and actual practice.

The conditions associated to Specific Risk as recommended according to Task 1 result were categorized as followed:

- Latent Failure,
- MMEL,
- Active Failure / Design Variability / Flight Condition / Operating Mode.
- Flight Time / Diversion Time / Flight Phase / At Risk Time.

The task groups working at the above-mentioned categories were guided by the following questions:

- What is addressed (regulation or guidance)?
- Why is it addressed (regulation or guidance recommendation background / preamble)?
- How is it addressed?
    - o Industry application / practices?
    - o Acceptability of next most critical failure on safe operation?
    - o Crew limitations and procedures?
    - o Reliability of critical components?
    - o Allowable exposure time?
    - o Meet average risk criteria of 25.1309?
    - o One failure away from catastrophe?

The following chapters give the results of Task 2. The results of each task group were detailed in tables addressing the above-mentioned questions.

6.2.1 Latent Failures Task

To meet the objectives of Task 2, the ASAWG established a task group to specifically address latent failures and to develop the table below.

The 6.2.1.1 table identifies Part 25 requirements, guidance, and other means that address latent failures, both directly and indirectly. The table also describes how latency is addressed by these criteria. The table identifies examples of application, including both FAA interpretation and industry practice.

In summary, the group found that there were a wide variety of approaches to addressing latency. Certain criteria apply to the latent side, or the active side, of failure combinations, or to the combined failure condition. Criteria also vary depending on whether the latent failure leaves the airplane one failure away from a catastrophic event. Different criteria are applied depending on the type of system being analyzed; for example, flight controls versus power plant installations. There may also be varying criteria for the same system depending on which rule is applied.

6.2.1.1 Latent Failures Task 2 table

→ Task 2 table.

Note: verify that you are on the "Latent" tab when opening the Task 2 table.

6.2.2 Active Failures & Design Variability Task

To meet the objectives of Task 2, the ASAWG established a task group to specifically address Active Failures, Design Variability, Flight Condition and Operating Mode and to develop the table below.

The table 6.2.2.1 identifies Part 25 and 33 requirements, guidance, and other means that address Active failures, Design Variability, Flight Condition and Operating Mode, both directly and indirectly. The table identifies examples of application, including both FAA interpretation and industry practice.

In summary, the group found that there were a wide variety of approaches to Active Failures. Certain criteria may apply to the active side or the latent side, of failure combinations, or to the combined failure condition.

The task of this group was to consider that the active failure occurred during a given flight. An active failure, which occurred before the flight, is addressed by the MEL or Aircraft Flight Manual.

In addition, the group realized that the airplane can be one failure away from a catastrophe. The group discussed several of these, but the easiest to grasp is the case on a two engine aircraft where one engine has failed. This, by itself, is minor or major, but now the aircraft is one failure away from a catastrophe, another failure that results in the loss of thrust from the other engine to maintain flight.

For design variability, quality escapes, as described in section 3 of this document, are outside the boundary of this document.

6.2.2.1 Active Failures & Design Variability Task 2 table

→ Task 2 table.

Note: verify that you are on the "Active & Design" tab when opening the Task 2 table.

6.2.3 MMEL Task

To meet the objectives of Task 2, the ASAWG established a Task Group to specifically address specific risk criteria related to the development of a Master Minimum Equipment List (MMEL). Table 6.2.3.1 was generated identifying; the regulations and/or guidance followed in developing an aircraft MMEL; the specific tailoring that an OEM may have utilized during the development of a MMEL; and just how the process addressed the specific risk issues related to the next most critical failure, crew limitations, reliability of critical components, allowable exposure times, quantitative dispatch times and being one failure from a potentially catastrophic condition.

In summary, all the OEMs are following the Flight Operations Evaluation Board (FOEB) process derived from FAA policy letters or a joint FOEB/JOEB process. Though the process that was followed was consistent across the industry, how the MMEL was actually derived and the data used to substantiate the recommended items in the MMEL varied. A common theme, however, did appear in that aircraft systems are becoming more and more functionally integrated using software and complex hardware logic devices to perform critical aircraft functions. Therefore qualitative design assurance processes, human factor aspects and common cause assessments are playing an increasingly important role with respect to MMEL relief.

6.2.3.1 MMEL Task 2 table

→ Task 2 table.

Note: verify that you are on the "MMEL" tab when opening the Task 2 table.

6.2.4 Flight & Diversion Time Task

To meet the objectives of Task 2, the ASAWG established a task group to specifically address Flight Time, Diversion Time, Flight Phase and At Risk Time. The task group documented what the primary issues were regarding the many regulations, guidance materials and industry examples, identified in Task 1.

The 6.2.4.1 table summarizes the associated regulations and background of each, along with industry application and practices. Also several questions were addressed regarding each of these examples. Some of these questions (written with MMEL in mind) are not applicable to flight time and diversion time and are so noted.

In summary, the flight time and diversion time team, notes that the ETOPS rule was recently revised and incorporates text that says it is necessary to meet 25.1309 under the ETOPS allowed configurations, so any changes that are made to 25.1309 is to cover ETOPS by default. Additionally, the item titled "Maximum flight time or maximum diversion time against mean flight time in Functional Hazard Assessments" is to address flight length (which may be driven by ETOPS flight times) assumptions in FHAs. The flight time and diversion time team recommends that all areas be further investigated in Task 3 and be considered within any specific risk discussion. Two items on the table, address basic assumptions made for a system or airplane in its functional hazard assessment with respect to flight length extremes. Assumptions made for shorter or longer than average flight lengths can in some cases result in severity of a failure condition being misclassified.

6.2.4.1 Flight & Diversion Time Task 2 table

→ Task 2 table.

Note: verify that you are on the “Flight” tab when opening the Task 2 table.

6.2.5 Task 2 Table – Excel Workbook

There are some incomplete fields with missing words in the tables from 6.2.1, 6.2.2, 6.2.3, and 6.2.4 due to the formatting issues, so that an MS Excel workbook is attached as follow:

ASAWG_Task 2
Table

[Click on the above link (icon) for opening the workbook]

6.3 Task 3

The ASAWG reviewed during Task 3 the results of Tasks 1 & 2 and determined the appropriateness, adequacy and consistency of the relevant existing regulations, existing guidance material, ARAC recommendations, and industry practices for airplane-level safety analysis. Task 3 demonstrated that a more consistent approach across systems is necessary.

The task groups (latent failure, active failure, MMEL, flight time) were guided by questions designed to help team members assess whether the existing regulations / guidance material / ARAC recommendations / industry practices are:

- Adequate?
- Appropriate?
- Applicable across systems?

The assessment was further guided by the following sub questions

- For adequacy:
  - Is the reason for the regulation/guidance given (why, preamble)?
  - Are all the relevant Hazardous and Catastrophic failure conditions covered?

- For appropriateness:
  - Is it commensurate with the potential level of risk?
  - Is it clear (unique interpretation)?
  - Is it a current requirement?
  - Is it practicable, i.e. achievable in itself and achievement verifiable?
  - Is it redundant with AC 25.1309 Arsenal Version?
  - Is it consistent with other rules and guidance related to the particular condition being reviewed?

- For applicability
  - Is it possible to be applied across all systems for this particular condition?
  - Is it possible to be applied across all systems for other particular conditions?

The task groups then identified the “fundamental issues” of the existing regulations / guidance material / ARAC recommendations / industry practices. “Fundamental issues” are the key approaches addressing Specific Risk.

For each “fundamental issue”:

- The current practice was summarized in Task 2 results.
- The pros and cons of the fundamental issues & current practices were identified, and supported by Task 3 questions / answers with regard to adequacy, appropriateness and applicability across systems.
- One or more recommendations were provided.

For each fundamental issue recommendations for Task 4 were developed and reviewed by stakeholders (industry & regulators). This review generated comments, the disposition of which is documented in this report.

The following chapters give the results of Task 3. The results of each task group were detailed in tables addressing the above-mentioned questions (adequacy, appropriateness and applicability across systems) and the fundamental issues.

6.3.1 Latent Failures Task

6.3.1.1 Introduction

The latent task group reviewed the various system safety processes for different systems like flight controls, thrust reversers, etc. to determine if specific risk (the risk on an individual flight or flights) is addressed and how. Further consideration was given to whether the methodologies were adequate, appropriate and applied consistently across systems.

From this review, the group identified common concepts / ideas relating to methodologies that addressed specific risk. These were then condensed into fundamental issues. The pro and cons of each fundamental issue were documented and reviewed. From this sub-team review and a subsequent review by stakeholders, general recommendations and additional guidance were identified for Task 4.

6.3.1.2 Task 3 Table

As directed by the tasking, the latent task group determined if the regulations and practices were adequate, appropriate and applicable across systems. The results are documented in the attached Task 3 table. This table was then used to perform the review described in section 6.3.1.3.

ASAWG_Task3
Table_Latent

6.3.1.3 Fundamental Issues

The latent task group reviewed current regulations and industry practices to determine common approaches that were used to address Specific Risk Concerns related to latency. After completing this review the task group took a brainstorming approach for allowing each member to voice his / her issues. Once everyone's issues were collected, they were condensed to the following four fundamental issues.

1 Limit Residual Probability (where "residual" is associated with the remaining risk following an assumed latent failure condition).

2 SRC Latent + 1 (addressing the question "What do you do" when a SRC latent failure condition leaves you one failure away from a catastrophe).

3 Definition of an SRC does not consider probability, leaving applicability too broad for Task 4 (need further criteria for when possible latency is not an SRC so that residual risk is not a concern).

4 Limit Latency.

6.3.1.4 Pros and Cons of Fundamental Issues

The pros and cons of each fundamental issue were discussed and documented in the attached Pros & Cons table. The table addresses each issue at a high level (is it worth implementing), and also focuses on the pros and cons of specific methodologies that incorporate this concept/issue. Based on these pros and cons, the information contained within the recommendation column resulted in the basic recommendations and additional guidance as discussed in 6.3.1.6 and 6.3.1.7, respectively.

ASAWG_ Pros and Cons Table_Latent

6.3.1.5 Stakeholder Review

The general recommendations and additional guidance (sections 6.3.1.6 and 6.3.1.7) were reviewed by stakeholders. This review generated comments, the disposition of which is documented in the attached Stakeholder Review table. Note that some of the stakeholder comments were marked as being applicable for consideration within Task 4 only.

ASAWG_Stakeholder Review_Latent

6.3.1.6 Recommendations for Task 4

Based on these pros & cons and recommendations from previous attached tables, general recommendations were made for each fundamental issue as follows:

6.3.1.6.1 First Fundamental Issue – Limit Residual Probability

- Establish a single consistent objective criteria and methodologies to limit the worst anticipated residual risk for catastrophic failure conditions.
- Determine whether limiting residual probability for any hazardous failure condition is warranted.

6.3.1.6.2 Second Fundamental Issue - SRC Latent + 1

- Give special consideration to this issue when addressing residual probability.

6.3.1.6.3 Third Fundamental Issue - Definition of an SRC

- Establish screening criteria (or filters) to determine which failure conditions will have additional specific risk criteria applied.

6.3.1.6.4 Fourth Fundamental Issue - Limit Latency

- Establish acceptable criteria to limit the exposure to latent failures which are not practical to eliminate.

  For example, limit the exposure to a latent failure in an inverse relationship to the failure rate such that maximum total probability of the latent failure is less than some TBD fixed value (e.g., some of the current practices use 1E-3).

  We recommend that this issue be carried forward as an and/or consideration with Fundamental Issue 1.

6.3.1.7 Additional Considerations for Task 4

The following additional considerations for Task 4 were derived from a review of the pros and cons associated with each fundamental issue. These additional considerations convey guidance for interpreting the intent of the general recommendations.

1 Limit the application of both residual risk and latency criteria chosen in Task 4 to Catastrophic failure conditions. Limiting residual probability for hazardous failure conditions may not be warranted and will need to be further addressed. [Note: Part 33 Engines worst case failure condition is "Hazardous" by definition of 33.75; there are some concerns with hazardous failure conditions which (a) border on being catastrophic (e.g. 1 in 50) or (b) result in 1 or 2 fatalities].

2 Limit the application of both residual risk and latency criteria (e.g., Fundamental Issue 3, see 6.3.1.6.3) chosen in Task 4 by probability and/or cutset order. Only a subset of possible configurations needs to be reviewed and will be determined in Task 4.

3 Establish both the residual risk and latency criteria chosen in Task 4 to set-up a control or acceptable level of risk for the subset population or fleet consistent with the current average risk criteria (e.g., do not drive 1E-9 failure combinations to 1E-12, etc.).

4 Limit the application of both residual risk and latency criteria so that they do not result in excessive analytical workload. Keep the criteria and process as simple as possible.

5 Minimize the architectural impact of both the residual risk and latency criteria chosen in Task 4 by considering the industry standard of reliability range (e.g. MIL-HDBK-217F, TELCORDIA, FIDES, NPRD and EPRD) for components. For example, take a dual failure cutset scenario -- neither the residual risk nor latency criteria should be outside the predicted reliability range of electronic components within that cutset.

6 Limit the application of both the residual risk and latency criteria chosen in Task 4 so that they do not routinely force significant increased model resolution (e.g., the use of LRU level basic events and associated MTBFs should be acceptable in fault tree models if justified by either a FMEA or a common cause analysis). Criteria should account for the existing conservatism in prediction methods like part count or part stress analysis used to calculate MTBFs when applied at the LRU level.

7 Limit the application of both the residual risk and latency criteria and policy chosen in Task 4 so that they do not adversely impact the risk of maintenance errors [e.g., increase the frequency such that traditional shop maintenance is moved to the flight line, increase the frequency of RII tasks (Required Inspection Items), etc.].

8 Establish in a clear, concise manner that both the residual risk and latency criteria chosen in Task 4 will recognize that exposure times are dependent upon when the failure occurs within a specific failure sequence (i.e., exposure times will change based on failure sequence).

9 Establish in Task 4 that “SRC Latent + 1” failure conditions that are catastrophic may be allowed, but should be limited via criteria which are as deterministic and objective as possible. If objective criteria are not attainable, resorting to more subjective case by case engineering judgments may be needed. Deterministic criteria examples are (1) reliance on the one remaining failure that has a failure distribution to some known confidence level, or (2) reliance on the integrity of a single component to those meeting standardized “critical parts” acceptance criteria (examples: special process controls on design, production, operation, and/or maintenance to limit failures of critical parts such as turbine disks or wiring), etc.

10 Establish in Task 4 criteria for addressing “SRC Latent +1” failure combinations that are consistent across systems, that do not drive unnecessary redundancy; and that do not drive unnecessary maintenance. Any SRC latent + 1 criteria is not to be defined so broadly that for example 90% of the time the cutset under evaluation could not meet the criteria and thus required additional redundancy.

11 Only allow latency which (a) cannot be eliminated or further reduced through practical means (i.e., like AC 25.1309-1A does now, indicate that relying on maintenance to detect latent failures is undesirable and should not be used in lieu of practical monitoring, etc.), [Note: may need to add more clarifying words in AC 25.1309 to define "practical" (e.g.. bring in technical and economic feasibility, design complexity, maintenance costs, regulatory burden and reliability)] and (b) meets an acceptable total probability criteria (e.g. less than 1E-3).

12 Establish in a clear, concise manner in Task 4 that exposure times equal to the life of the airplane in 3rd order cutsets (or 4th order cutsets, or 5th order cutsets, etc.) will not be prohibited.

6.3.2 Active Failures Task

6.3.2.1 Introduction

The active task group examined the current regulations and guidance material identified in Task 2.

6.3.2.2 Task 3 Table

As directed by the tasking, the sub-team determined if the regulations and practices were adequate, appropriate and applicable across systems. The results are documented in the attached Task 3 table. This table was then used to perform the review described in section 6.3.2.3.

ASAWG_Task 3
Table_Active

6.3.2.3 Fundamental Issues

To meet the objectives of Task 3, the Active task group identified the following fundamental issues:

- After the first failure, you are still more than one more failure away from a catastrophe (not universal for all situations, e.g. dual channel system),
- After the first active failure, there are ways to control (identify, quantify) the residual risk,
- Assure compliance when considering the effects of aging and wear.

6.3.2.4 Pros and Cons of Fundamental Issues

Upon review of the fundamental issues, the group concluded that the first fundamental issue was a subset of the second, and only carried the second and third fundamental issues forward. Pros and cons of current practices for the fundamental issues were then discussed, and those results are presented below:

6.3.2.4.1 "After the first active failure, there are ways to control (identify, quantify) the residual risk"

"Pros" Attributes:

- Regulations/guidance control (identify, quantify) the residual risk after an active failure

"Cons" Attributes:

- Current practices for limiting residual risk are inconsistent across systems.
- Inconsistent quantitative requirements for residual risk may:
    - lead to unbalanced system architectures (e.g. in case of extremely remote required by 25.981)
    - result in the average risk being significantly below the 1E-9/1E-7 criterion (i.e. unnecessary additional redundancy),
    - lead to unnecessary additional maintenance,
    - drive reductions in maintenance intervals that would have a net adverse impact on safety (e.g. cause critical maintenance to be moved from the hanger to the flight line)

6.3.2.4.2 "Assure compliance when considering the effects of aging and wear"

"Pros" Attributes:

- 25.1309 was identified as the place where aging and wear are currently addressed. 25.1309 considers aging, wear by assuming a constant failure rate based on service history that includes aging and wear.

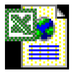
- The analysis should establish life limits or other restrictions to ensure that the failure rate used in the analysis is constant.
- Doing an analysis using a time dependent failure rate is not required if the applicant has established life limits or other restrictions to ensure the failure rate is constant.
- 25.1309 and 25.981 are consistent with regard to aging and wear aspects.

“Cons” Attribute:

- System component life limits established to protect against aging and wear out are not documented consistently.

6.3.2.5 Stakeholder Review

The general recommendations were reviewed by stakeholders. This review generated comments, the disposition of which is documented in the attached Stakeholder Review table.



ASAWG_Stakeholder Review_Active

6.3.2.6 Recommendation for Task 4

6.3.2.6.1 Recommendation for the first fundamental issue

The regulations address this fundamental issue by using different quantitative values for different systems. Today's regulations / guidances are inconsistent and a more standardized approach is recommended.

This approach should:

- allow for different residual risk criteria for two channel systems and for more than two channel systems,
- not result in the average risk being significantly below the 1E-9/1E-7 criterion (i.e. unnecessary additional redundancy),
- not lead to negative consequences for maintenance,
- continue to allow qualitative analysis for simple and conventional systems,
- be consistent with the latent failure sub team recommendation(s).

6.3.2.6.2 Recommendation for the second fundamental issue

For aging and wear, the current regulations / guidance require further review. AC 25.1309 Arsenal currently states, "Average Probability per Flight Hour should be estimates of the mature constant failure rates after infant mortality and prior to wear-out …" For mechanical components whose probability of failure may be associated with non constant failure rates, reliability analysis may be used to determine component life limits.

In Task 4, develop recommendation for consistently documenting system component life limits that are necessary to protect against aging and wear out.

6.3.3 MMEL Task

6.3.3.1 Introduction

A review of FAA, TCCA and JAA/EASA guidelines and policy material on the development and approval of the MMEL was conducted in Task 2. Task 3 reviewed the results of Task 2 to determine the appropriateness, adequacy and consistency of the existing guidance and policy material relating to the development and approval of the MMEL. This task was also intended to determine if a consistent approach to MMEL development is needed with regard to Specific Risk.

The MMEL/MEL is the authority approved document that allows dispatch of the airplane with inoperative equipment. The SR tasking is concerned with the conditions where the airplane does not meet the average reliability requirements of 25.1309 when dispatched with inoperative equipment.

The current processes employed by OEMs and Authorities are:

- The OEMs currently provide SR assessments on selected systems based on experience and technical knowledge

  (a) All the OEMs represented in the ASAWG performed quantitative analysis on all or selected systems to support entry on a proposed MMEL.

  (b) The analysis methodology is consistent with current accepted arsenal AC25.1309 recommendations for reliability analysis with only the selection and approval criterion differing
- Selected MMEL items may be assessed during Function and Reliability (F&R) flight testing conducted as part of the operational evaluation process.
- The flight standards process is independent of the certification process.
- Selected (proposed) MMEL items are reviewed by the FOEB/JOEBs using engineering cab simulation.
- Selected (proposed) MMEL items are reviewed by engineering analysis using both certification data and requested analyses.
- In service events are constantly monitored by the FOEB/JOEB chairman to ensure continued acceptability of individual MMEL items.

The MMEL group finding in this task is that SR is not the main concern during MMEL dispatches. Far more important are the airplane’s operational characteristics in its dispatch condition as well as its operational characteristics after the next worst case failure.

After consideration of these current processes, the MMEL group conclusion is that the current policies and practices concerning the development and approval of the MMEL over the past several decades, has consistently demonstrated a high level of reliability and comprehensiveness in maintaining the necessary safety margins that both the engineering and operations communities have come to expect and require.

6.3.3.2 Task 3 Table

The Task 3 tables associated to the MMEL Task Group can be found at the link below. These include responses from the stake holders to the questions of Adequate, Appropriate and Applicable across Systems. In the case of the latter of these questions "Applicable across Systems", this question and some of the questions used to determine if it was "Appropriate" were considered not to be applicable to the MMEL case. The responses were used to help derive the task group's fundamental issues.

ASAWG_Task 3 Table_MMEL

6.3.3.3 Fundamental Issues

The MMEL Task Group identified two "fundamental issues" from the application of the existing regulations/guidance material and various industry practices used in the development and supporting rationale of a MMEL as defined in the Table above. The fundamental issues identified are:

1. There is no explicit guidance on methodology for conducting specific risk evaluation for dispatch under a MEL ("Limiting Residual Risk").

2. The explicit guidance / methodology on the application of the next worst failure criteria when developing a MMEL ("One Failure Away").

6.3.3.4 Pros and Cons of Fundamental Issues

During the consolidation of the fundamental issues at the ASAWG level the two MMEL issues were placed under the headers of "Limiting Residual Risk" and "One Failure Away". Each fundamental issue was then reviewed with the "Pros" and "Cons" identified. These attributes for each review are:

6.3.3.4.1 Limiting Residual Risk

"Pros" Attributes:

- In general, the application used by the various OEMs relates back to the 25.1309 criteria, and then relies on a qualitative review to accept variances. This permits adaptability while still providing regulatory review in the loop.
- The criterion used by large transports appears to align well with some of the quantitative criteria by the other task groups. As an example if 1E-7 criteria is acceptable provided you are not one random system failure away then you potentially have a balanced system that would require two random failures

(less than 1E-3 each) which should be acceptable depending on the outcome from the Latent and Active groups.

“Cons” Attributes:

- There currently is no design guidance, therefore, it lets the various OEMs and authorities determine what is appropriate.
- The application by the various OEMs to require full compliance to 25.1309 criteria with P=1 is conservative. There currently is no design regulatory guidance so it lets the various OEMs and Certification Offices to determine what is appropriate, this provides a disparity across OEMs.
- The application by the various OEMs to require full compliance to 25.1309 criteria with P=1 is conservative but may not be consistent with other conditions such as latent failures.

6.3.3.4.2 One Failure Away

“Pros” Attributes:

- For systems the practice makes sense irrespective of the probability of the next single failure. This is typical because the best failure rates you see systems exhibit is between 1E-4 and 1E-5.
- Prior to dispatch (while on the ground) the discrepancy is known and if deemed necessary, repair can be made.

“Cons” Attributes:

- The specific conditions related to interaction of systems and structure may be a peculiarity but one that this black and white philosophy does not cover well. In structural conditions where the next failure may be on the order of 1E-7 it may make sense to permit a short term dispatch criteria with one failure away if you know the failure is not random in nature but exhibits wear out or fatigue characteristics that are very much controlled, and/or the exposure window is quite limited.

6.3.3.5 Stakeholder Review

Preliminary recommendations that were developed from the above “Pros” and “Cons” were reviewed by stakeholders. This review generated comments, the disposition of which is documented in the attached table.

ASAWG_Stakeholder
Review_MMEL

The following recommendations account for the comments provided in the above Table.

6.3.3.6 Recommendation for Task 4

The final evaluation of the current policies and practices implemented by OEMs and the various regulatory organizations concerning the development and approval of the MMEL over the past several decades, has consistently demonstrated a high level of reliability and comprehensiveness in maintaining the necessary safety margins that both the engineering and operations communities have come to expect and require. However, if a numerical analysis is used to support a MMEL proposed item some MMEL policy guidance would be beneficial to ensure consistency in approaches and methodologies.

During Task 4, it is recommended that a standardized methodology be prepared for Flight Standards to review and consider in their guidance and policies on MMEL development. As a minimum, the following attributes should be considered when developing this MMEL methodology:

- When specific risk should be used to support an individual MMEL item proposal.
- Consideration of MMEL dispatches when the next worst case failure could lead to a hazardous / catastrophic conditions.
- Architectural considerations of complex systems.

6.3.4 Flight & Diversion Time Task

6.3.4.1 Introduction

The Flight Time Team reviewed during Task 3 the results of Tasks 1 & 2 to determine the appropriateness and adequacy of the relevant existing regulations, existing guidance material, ARAC recommendations, and industry practices for airplane-level safety analysis. The intent of this review was to determine if a more consistent approach across systems is necessary.

The flight time task group was guided by questions designed to help team members assess whether the existing regulations/guidance material/ARAC recommendations/ industry practices are adequate, appropriate and applicable across systems.

As described above the flight time task team evaluated whether the available regulations and guidance material were adequate to be applied across systems. This included an assessment of whether the regulation or guidance was clearly written, current, practical and verifiable. The regulations, guidance and practices were also reviewed to evaluate whether it would be appropriate to apply a regulation that may have been written for a specific issue, across systems. This included a review of preamble material that describes why the regulatory material was written. Applicability of the regulations included an assessment of whether it makes sense to broadly apply the existing regulations across systems.

The flight time team assessed eight areas of regulation and guidance using the attached Task 3 table. Ultimately, we used this spreadsheet to look for common themes across the rows and columns for the eight areas to distill into the fundamental issues outlined below. We also reviewed the spreadsheets of the other teams to assure that the fundamental issues identified by the flight time team were not redundant.

ASAWG_Task 3
Table_Flight

Based on this assessment, it was concluded that a more consistent approach is necessary to avoid undue burden on the applicant and regulatory authorities. Regulations which have varied approaches to specific risk can lead to confusion and misapplication of rules across OEMs, Regulatory agencies, and suppliers. A more consistent approach will also assure that the level to which specific risk is regulated is warranted.

6.3.4.2 Fundamental Issues

The following three fundamental issues are recommended to be moved forward to Task 4.

1. The first fundamental issue is that the FHA needs to consider flight length and flight phase as relevant to the intensifying hazard class severity.

2. The second fundamental issue is to assess risk based on maximum flight time and maximum diversion time instead of average flight time.

3. The third fundamental issue is to assess risk during actual at-risk time versus normalizing by flight length (AC 25.1309-1A vs. AC 25.1309 Arsenal Version).

6.3.4.3 Pros and Cons of Fundamental Issues

6.3.4.3.1 Intensifying factors for hazard class severity.

In the current practice for 25.1309, the FHA considers intensifying factors in assigning hazard classification.

“Pros” Attributes:

The hazard classification of a failure condition is complete (and correct) when both operational and environmental factors are considered along with the failure(s). The definition of "failure condition" in AC25.1309-1A and Arsenal clearly includes consideration for these factors. More importantly, service history clearly shows the need to take these factors into account and the current practice allows engineering judgment when considering intensifying factors and hazard classification.

“Cons” Attributes:

The FHA guidance is not clear on how many intensifying factors, of which flight length may be one, must be considered in combination. With enough "intensifying factors" combined, FHA hazard classifications could be unnecessarily raised, resulting in unreasonably high development assurance levels and increased complexity if added redundancy is required to comply with unrealistic hazard stack-ups. In addition, the distinction between hazardous and catastrophic is difficult to achieve, given existing guidance due to numerous possibilities of intensifying factors.

6.3.4.3.2 Risk based on maximum flight time and maximum diversion time instead of average flight time.

In the current process for 14 CFR 25 Appendix K the exposure times must consider maximum mission time and maximum diversion time for both group 1 and 2 systems and they must meet 25.1309 criteria per Appendix K25.1.1. In addition, in 25.1309, only average times are considered in numerical analysis.

“Pros” Attributes:

Using the maximum flight time is usually, but not always, conservative for all cases, so current practice results in most conservative approach.

“Cons” Attributes:

The 25.1309 probability criteria is based on the average flight, using maximum flight length for all cases which results in unnecessarily conservative designs. Also, the available guidance is unclear on how “ETOPS significant systems” should be analyzed.

6.3.4.3.3 Risk during actual at-risk time versus normalizing by flight length (AC 25.1309-1A vs. AC 25.1309 Arsenal Version).

The current process in AC 25.1309-1A 10.b.2 states that for a function which is used only during a specific flight operation; e.g., takeoff, landing, etc., the acceptable probability should be based on, and expressed in terms of, the flight operation's actual duration.

AC 25.1309 Arsenal Appendix 3.b.2 states that if the failure is only relevant during certain flight phases, the calculation should be based on the probability of failure during the relevant "at risk" time for the "Average Flight". The "at risk time" probability is then normalized by dividing by the average flight time.

“Pros” Attributes:

No pros were identified for having two different sets of guidance.

“Cons” Attributes:

The currently approved EASA and FAA guidance is in conflict with each other and requires harmonization. If only the Arsenal criteria were used per flight hour calculations under estimate the risk for those items where the exposure is concentrated in a segment of the flight, for instance takeoff and landing (where most accidents occur). If only the AC25.1309-1A criteria were used, by requiring short flight phase exposure times to have to meet the same criteria, it unfairly penalizes systems critical during short phases and is more conservative than average risk criteria based on per flight hour. It could also result in increased complexity if added redundancy is required.

6.3.4.4 Stakeholder Review

6.3.4.4.1 Intensifying factors for hazard class severity.

During stakeholder review, there were several comments on each fundamental issue. A comment was made that extreme care should be taken in any clarifying language not to change the definition of the hazard classifications. This was noted in the Task 4 issues to consider for this item. Other comments to this fundamental issue were discussed and dispositioned without change to the recommendation.

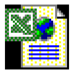
6.3.4.4.2 Risk based on maximum flight time and maximum diversion time instead of average flight time.

During stakeholder review, there were three comments on this fundamental issue. One comment was that the working group should consider the definitions as per draft AC25.1535-1X (i.e. max. flight time, max ETOPS mission time, average ETOPS mission time, max diversion time) and using them consistently in the recommendation. This comment was incorporated into the recommendation. The other comments were to remember to consider impact on various operational rules in Task 4. This was incorporated into the recommendation as well. The other comment to this fundamental issue was discussed and dispositioned without change to the recommendation.

6.3.4.4.3 Risk during actual at-risk time versus normalizing by flight length (AC 25.1309-1A vs. AC 25.1309 Arsenal Version)

During stakeholder review, there were two comments on this fundamental issue. The comments lead to a clarification of the original recommendation to delineate that the

AC 25.1309 Arsenal Version remained acceptable for average risk calculation, and Task 4 will only look at those conditions where specific risk criteria need to be developed. The recommendation was revised to reflect this change.



ASAWG_Stakeholder
Review_Flight

6.3.4.5 Recommendation for Task 4

6.3.4.5.1 Intensifying factors for hazard class severity

The recommendation to resolve this first fundamental issue is to add text to AC 25.1309 Arsenal Version to clearly lead to the conclusion that FHA needs to consider intensifying factors expected in the approved envelope, including flight length, flight phase, and diversion time. The AC should provide qualitative guidance on when combinations of intensifying factors should be considered, and when combinations of factors can be considered to not be reasonable (e.g. icing+130 deg ambient temp). In addition, additional guidance should be added to clarify distinction between hazardous and catastrophic failure conditions without changing the hazard classification definitions.

6.3.4.5.2 Risk based on maximum flight time and maximum diversion time instead of average flight time

The recommendation for the second fundamental issue is that the maximum mission time and maximum diversion time should be used for hazard classification in functional hazard assessments. System capability, capacity and performance should be sized for maximum mission time and maximum diversion time as appropriate. Numerical analysis should use average flight time for the fleet under consideration. For ETOPS specific risk, this means Group 1 and 2 systems both use the average ETOPS mission time in their probability calculations. Diversion times should use the maximum diversion time of all flights in the probability calculations. Both ETOPS and non-ETOPS calculations should meet current 25.1309 criteria.

Various operational rules will be considered in development of the final recommendation in Task 4. Recommendation will be coordinated for consistency with ETOPS EASA NPA and Draft FAA AC (this clarifies the MOC, no rule changes proposed).

6.3.4.5.3 Risk during actual at-risk time versus normalizing by flight length (AC 25.1309-1A vs. AC 25.1309 Arsenal Version)

The recommendation to resolve the third fundamental issue is to use AC 25.1309 Arsenal Version paragraph 11.e(1) for average risk. For specific risk, determine if AC 25.1309-1A criteria should be used or other criteria developed for latent and active failures.

6.4 Task 4

The ASAWG reviewed during Task 4 the results of Tasks 1, 2 & 3 and worked on change recommendations for existing regulations, existing guidance material, ARAC recommendations, and industry practices for airplane-level safety analysis. The change recommendations are mainly focusing on the “fundamental issues” identified during Task 3.

The ASAWG concluded on change recommendations for the Latent & Active Failure Task, Aging & Wear Task, the MMEL Task and the Flight & Diversion Time Task. The change recommendations are related to guidance material and regulations as appropriate. The following chapters give the results of Task 4. The results of each task group are covering benefits of the recommendations, applicability of the recommendations, the recommendations with rationales, alternatives considered (if any) and dissenting opinions (if any). The final Task 4 change recommendations were established by taking into account comments from all organizations as received during Task 4.

6.4.1 Latent Failure Task

In accordance with the ASAWG tasking, the ASAWG assessed the specific risk aspects of latent failures and developed recommendations.

Previous ARAC harmonization working groups like Flight Controls, Power Plant Installations, and Systems Design and Analysis, and regulatory agencies, produced varying recommendations regarding the safety of critical airplane systems. These recommendations have found their way into the certification of several recent aircraft through Issue Paper (IPs) and/or Certification Review Items (CRIs). Although, the subject of latent specific risk analysis was addressed, the recommendations were not consistent. The changes recommended in this section start from the proposals of those working groups because many of these recommendations are already being complied with by the Industry. However, the ASAWG only reviewed the areas related to specific risk and therefore only those changes are discussed and evaluated for benefits and cost. The cost / benefits section of this report does not account for the safety benefits and/or cost that had already been identified by the previous working groups.

After reviewing the existing regulations and the recommendations from the various harmonization-working groups, the ASAWG established a change recommendation for FAR/CS 25.1309(b) and AC/AMC 25.1309, sections 9.b.(6) & 9.c.(6). This change recommendation shall serve as a mean to ensure a standardized consideration of latent specific risk across all systems. Consequently other material like regulations, AC/AMC, ARAC recommendations still considering latent specific risk with different approaches have to be changed to point to the revised FAR/CS 25.1309(b) and AC/AMC 25.1309, sections 9.b.(6) & 9.c.(6). Without these changes as well as the recognition that any future ARAC tasks to system level working groups should always point to the revised FAR/CS 25.1309(b) and AC/AMC 25.1309 to ensure the benefits defined in Section 6.4.1.3 of this report are met.

This document collects the rationale for each proposed regulation change recommendation to FAR/CS 25.629, FAR/CS 25.671, FAR/CS 25.901, FAR/CS 25.933, FAR/CS 25.981, and FAR/CS 25.1309(b). In addition, the rationale for each proposed related guidance change recommendation is provided. This rationale is intended to identify the limits of the rules and the guidance that were developed under with the intent to prevent misunderstanding and requirements creep in the future. This preamble also provides a storage facility for describing why a change is being made, what alternatives were considered and what is the benefit (safety or otherwise) of each change.

The key benefit Industry saw after several years of review and discussion was harmonization and consistency across all systems and between various regulation bodies. Early, in the Task 4 efforts TAEIG identified to the ASAWG that documented safety benefits would be difficult if not impossible and the focus should be placed on harmonization and consistency. The benefits identified by the working group of implementing the proposed changes would be invalidated without the complete implementation of all the changes in total by both the FAA and EASA. Therefore, it was a unanimous position from manufacturers that the proposed changes are either implemented in total or should not be implemented at all. Unlike previous working groups that were tasked to respond to a specific event or threat that had occurred, this effort is more of a harmonization across the aircraft and regulatory bodies. The identification of potential measurable safety benefits would require a forecast of a potentially hazardous or catastrophic event, therefore no safety benefits were identified.

The term *"… on the order of 1/1000 or less"* in FAR/CS 25.1309(b)(4)(ii) was selected over a qualitative term such as probable, because the historical use of this term in the current regulations and guidance material are not consistent. In some cases it is meant to define conditions that are between 1E-3 and 1E-5 while other uses in the same guidance to define it as conditions between 1.0 and 1E-5. The identification of a new term that would take on the meaning of *"on the order of 1/1000 or less"* was also entertained; however, this was abandoned because of the potential confusion between "probable" and this new term. A specific number was not used because it was felt by all and with several examples provided where existing systems, that had substantial field history and mature production were slightly higher than the 1E-3 criterion. The statement "on the order" would enable the manufactures to present an argument to the authorities using state-of-the-art, maturity, statistical certainty, etc…, when the number exceeds the 1E-3 criterion.

The criteria defined under FAR/CS 25.1309(b)(4) is not applicable to single failures in combination with operational or environmental conditions leading to a catastrophic effect, because it is already covered by FAR/CS 25.1309(b)(1)(ii) and its associated guidance addressed in Arsenal Draft of AC/AMC 25.1309 (e.g. section 11(g)).

The limitations to include this criteria to only catastrophic conditions and failure conditions of two, either of which is latent and the combined probability that exceeds 1E-12/FH was established based on a cost benefit analysis. A thorough review of existing system level fault trees identified only those cut-sets associated with two or less failure conditions being critical. Hazardous conditions were excluded for the following reasons:

- Single failures are allowed to be Hazardous, so there was no regulatory basis for adding hazardous criteria for single plus latent condition.
- Given the probabilities being considered for catastrophic conditions, any levels chosen for hazardous would give insignificant, if any, improvement relative to the amount of work involved.
- Hazardous events will be corrected through in-service processes with procedures, and guidelines in place to correct them.
- Effort would be diluted on issues that are less significant, instead of focusing limited resources on the most important issues.
- Existing regulations with specific risk criteria (e.g. FAR/CS 25.671, 25.981, 25.933, etc.) do not deal with hazardous conditions.

Finally, the 1E-12/FH limit criterion was established as a statistical fall out of the major criterion to limit residual risk and the one in a thousand criterion to limit latency.

Initially, active failures were included under the review of specific risk. However, based on the followings, it was determined that the existing average risk requirements of FAR/CS 25.1309 and associated guidance already adequately addressed these issues:

- Active failures by their nature are not hidden and will be responded to by maintenance prior to the next flight; therefore, no flight will start one failure away from a catastrophic condition.
- Active-active conditions are adequately covered by average risk assessments because economics prevent unbalanced systems with one item having a high failure rate.

In addition, regulations such as FAR/CS 25.783 and FAR/CS 25.1709 that have specific design criteria related to these active failures were reviewed, but later excluded from any proposed changes. The Working Group decided that it was appropriate for specific active failure and latent failure design guidance that were generated from lessons learned to be retained in the specific system paragraphs and further reference for compliance to the 25.1309 was not required.

Finally, because these changes provide no measurable safety reduction at the aircraft yet, include the general system requirements provided in FAR/CS 25.1309 that are applicable across all systems, they should not be applied retroactively and should only include those certifications that require a new certification basis.

6.4.1.1 Applicability of the Recommended Rules/ACs

These changes will apply to new TC or STC, if required according to change product rule, and will not be applied retroactively.

6.4.1.2 The Recommendations

6.4.1.2.1 Change recommendations for FAR/CS 25.1309(b) and Arsenal Draft of AC/AMC 25.1309, Sections 9.b.(6) & 9.c.(6).

- Add to FAR/CS 25.1309(b).

  "25.1309(b)(4) For each catastrophic failure condition that results from two failures, either of which is latent for more than one flight, it must be shown that -

  (i) Given any single latent failure has occurred, the combined probability due to any subsequent single failure is remote; and

  (ii) The probability of occurrence of the latent failure is on the order of 1/1000 or less."

- Add to Arsenal Draft of AC/AMC 25.1309, Section 9.b.(6).

  Latent Failure Conditions

  In addition to the general guidance for significant latent failures elsewhere in this AC/AMC, the following evaluations are performed where a latent failure combination (i.e. one or more latent failures) can be present for more than one flight and leave the airplane one failure away from a catastrophe. Failure combinations (i.e. one evident and one or more latent failures) smaller than 1E-12/FH provide design margin inherently greater than that established by the criteria below and therefore do not need to be considered.

  Whenever practical, these latent failures should be avoided. Means of avoidance include but are not limited to: eliminate the latent failure as discussed in paragraph 9(c) or add redundancy.

  Where these latent failures are not avoided each case should be highlighted to the authorities as early as possible. For those cases where it is specifically requested by the authorities, the safety assessment should explain why avoidance is not practical, and provide supporting rationale for the acceptability. Rationale should be based on past experience, sound engineering judgment or other arguments, which led to the decision not to implement other potential means of avoidance.

  When a case is limited to two failures, either of which is latent that cannot practically be avoided, compliance with FAR/CS 25.1309(b)(4) provides acceptance criteria. Two criteria are implemented in the rule, limit latency and residual risk. Limit latency is intended to limit the time of operating with a latent failure present. This is achieved by requiring the average probability for the latent failure to be on the order of 1E-3 or less. Residual risk is intended to limit the average probability per flight hour of the failure condition given the presence of a single latent failure. This is achieved by defining the residual risk to be remote.

Residual risk is the sum of single active component(s) that have to be combined with the single latent failure to result in the Catastrophe.

Appendix A section 6.4.5.4 gives simplified examples explaining how the limit latency and residual risk analysis might be applied.

- Change to Arsenal Draft of AC/AMC 25.1309, Section 9.c.(6).

  The use of periodic maintenance or flight crew checks to detect significant latent failures when they occur is undesirable and should not be used in lieu of practical and reliable failure monitoring and indications. Where this is not accomplished, ~~the system safety assessment should highlight all those significant latent failures that leave the airplane one failure away from a failure condition classified as catastrophic. These cases should be discussed with the FAA/JAA as early as possible after identification~~ see paragraph 9.b.(6) for guidance.

Rationale:

In accordance with the ASAWG tasking, the ASAWG assessed the various regulations, AC/AMC, ARAC recommendations and industrial practices in order to determine if and how latent specific risk is addressed in the frame of system safety processes for different systems. Further consideration were given to whether the methodologies were adequate, appropriate and applied consistently across systems. ASAWG came to the result that a consistent approach across systems is not given and has to be established to assure a standardized approach across systems needed to properly evaluate system safety at the aircraft level. The FAR/CS 25.1309 is the natural candidate to host the standardized approach for latent specific risk across all systems having also in mind that the tasking boundaries exclude specific risk associated with airframe structures and exclude methodologies not covering airplane certification.

This standardized approach for latent specific risk takes into account the following aspects in accordance with the ASAWG tasking mission, the established specific risk definition and the identified fundamental issues around latent specific risk:

- Assure a warranted level of specific risk regulation to avoid over- or under-regulation.
- Concentrate on the specific risk of concern when the airplane is one failure away from a catastrophe on a given flight due to latent failures.
- Give special consideration to the avoidance of latent failures, whenever practical.
- Give special considerations to the avoidance of undue burden on the applicant and regulatory authorities.
- Do not address latent specific risks, if they lead to a failure condition of Hazardous, in accordance with existing regulations and recommendations related to latent specific risk.
- Do not address specific risks, if they lead to a failure condition of Major or less severe criticality, in accordance with the ASAWG tasking boundaries.

- Establish a single consistent objective quantitative criteria and methodology to limit the worst anticipated residual risk for catastrophic failure conditions given any single latent failure has occurred.
- Establish a single consistent objective quantitative criteria and methodology to limit the worst anticipated latency for catastrophic failure conditions.
- Establish screening criteria (or filters) to determine which failure conditions will have additional specific risk criteria applied.
- Prevent the average risk being significantly below the 1E-9/FH criterion (i.e. unnecessary additional redundancy).
- Prevent negative consequences for maintenance.
- Continue to allow qualitative analysis for simple and conventional systems.

When developing the new requirements for FAR/CS 25.1309(b)(4) there was a desire to keep the acceptance criteria for both limit latency criteria and limit residual risk in the qualitative terms currently being used by the Industry. This would provide the continued application of what the definition of "on the order of" meant when saying must satisfy the remote or improbable conditions. However, in reviewing the current AMC 25.1309 or the proposed Arsenal Draft of AC/AMC 25.1309 the term probable had two meanings. Therefore it was decided to use "… on the order of 1/1000 or less" in lieu of the term probable.

The decision to limit the specific risk criteria to only two order cut sets was made after an extensive review by industry was conducted on several certificated aircraft. The system level fault trees were reviewed for conditions involving latent failure events. There was a significant difference in the number of cut sets that had to be reviewed between two and three order cut sets yet the additional work did not identify any additional concerns. From these reviews, the cut off criteria of 1E-12/FH and only reviewing two order cut sets was established to limit the amount of analysis required to show compliance to the new specific risk criteria. The average risk analysis adequately protects the three or more failure combinations.

Industry was concerned about the proliferation and use of the qualitative statements in AC/AMC 25.1309 Section 9.b.(6) *"Whenever practical, these latent failures should be avoided. Means of avoidance include but are not limited to: eliminate the latent failure as discussed in paragraph 9.c or add redundancy"* beyond the intent of the Working Group. Therefore the third paragraph was added to stress that there is known latent conditions that continue to reside in aircraft systems that have proven over time to be impractical to design around or eliminate, and thus the quantitative criteria of 14CFR 25.1309(b)(4) was ultimately the adequate mitigation.

The criteria defined under FAR/CS 25.1309(b)(4) is not applicable to single failures in combination with operational or environmental conditions leading to a catastrophic effect because it is already covered by FAR/CS 25.1309(b)(1)(ii) and its associated guidance addressed in Arsenal Draft of AC/AMC 25.1309 (e.g. section 11(g)).

Finally, it was recognized that the introduction of a new aircraft level requirement for specific risk may introduce potential confusion on what check interval should drive the CCMR as discussed in AC/AMC 25.1309 Section 12.c. Because the limit latency criteria of on the order of 1/1000 or less is in addition to the average risk criteria, the one that produces the lowest check interval should be used. The Working Group thought this was already clear in the AC/AMC because there were no exclusions. Therefore, no change was made to Section 12.c of the AC/AMC.

6.4.1.2.2 Change recommendations in the area of FAR/CS 25.629, FAR/CS 25.671, FAR/CS 25.901, FAR/CS 25.933 and FAR/CS 25.981

- Change AC/AMC 25.629-1A, Section (c)(3)(c):

  "Any damage or failure conditions considered under FAR25.571, FAR25.631 and FAR25.671. The actuation system minimum requirements should also be continuously met after any combination of failures not shown to be extremely improbable. ~~(occurrence less than 1E-9 per flight hour). However, certain combinations of failures, such as d~~ Loss of dual electric system or dual hydraulic systems are not normally considered extremely improbable.~~, or any single failure in combination with any probable electric or hydraulic system failure (FAR25.671), are not normally considered extremely improbable regardless of probability calculations. The reliability assessment should be part of the substantiation documentation. In practice, meeting the above conditions may involve design concepts such as the use of check valves and accumulators, computerized pre-flight system checks and shortened inspection intervals to protect against undetected failures."~~

  Rationale:

  The advisory circular (AC) guidance requires the applicant when reviewing certain dual failure combinations to consider adding additional redundancy or reducing inspection intervals. The new 25.1309 limit latency requirement provides quantitative guidance for determining whether the inspection interval is appropriate. This will ensure consistent application. With regard to adding redundancy for single active plus latent failure combinations equivalent language has been added to AC 25.1309 *"…Whenever practical, these latent failures should be avoided. Means of avoidance include but are not limited to eliminate the latent failure as discussed in paragraph 9.c. or add redundancy…"*

  However, the ASAWG decided not to consider changes to FAR/CS 25.629. The ASAWG believes that the guidance for validating failure rates and other assumptions in the AC/AMC 25.1309 is sufficient for ensuring adequate redundancy in these situations. For example, a 25.1309 analysis would typically conclude that dual generator or dual hydraulic systems are not extremely improbable.

- Change FAR/CS 25.671(c)(2):

  (c) The airplane must be shown by analysis, test, or both, to be capable of continued safe flight and landing after any of the following failures, including jamming, in the flight control system and surfaces (including trim, lift, drag, and feel systems) within the normal flight envelope, without requiring exceptional

piloting skill or strength. Probable failures must have only minor effects and must be capable of being readily counteracted by the pilot.

(2) Any combination of failures not shown to be extremely improbable. Furthermore, the flight controls must comply with FAR25.1309(b)(4). This paragraph excludes failures of the type defined in (c)(3).~~excluding jamming (for example, dual electrical or hydraulic system failures, or any single failure in combination with any probable hydraulic or electrical failure).~~

- Change FAR/CS 25.671(c)(3)(iii):

(c) The airplane must be shown by analysis, test, or both, to be capable of continued safe flight and landing after any of the following failures, including jamming, in the flight control system and surfaces (including trim, lift, drag, and feel systems) within the normal flight envelope, without requiring exceptional piloting skill or strength. Probable failures must have only minor effects and must be capable of being readily counteracted by the pilot.

(3)Any failure or event that results in a jam of a flight control surface or pilot control that is fixed in position due to a physical interference. The jam must be evaluated as follows:

(iii) In the presence of a jam considered under this sub-paragraph, any combination of failures that are catastrophic shall comply with FAR25.1309(b)(4).~~additional failure states that could prevent continued safe flight and landing shall have a combined probability of less than 1 in 1000.~~

- Change Post TAEIG draft AC/AMC 25.671:

If the guidance defined under the AC/AMJ 25.671 post TAEIG draft is adopted then it is recommended that all references to specific risk be deleted and a pointer be provided to the proposed revision to AC/AMC 25.1309 (see attached).

C:\Safety\TAEIG WG
Final Report\Latent\A

<u>Rationale:</u>

This regulation is associated with an issue paper and an ARAC FCHWG recommendation that implement limit latency and/or residual risk methodology. The ARAC FCHWG recommendation requires that in the presence of any single failure the sum of all remaining failures meet 1/1000 probability. This is a limit latency and residual risk requirement. The issue paper requirement requires that for any single failure in each individual failure sequence (e.g. cut set) that the remaining failures in that sequence be Remote. The issue paper requirement is a residual risk only requirement.

These previous means of compliances provide different criteria and different methodologies for calculating the criteria. The new 25.1309 regulation adopts both limit latency and residual risk criteria. The residual risk numerical objective of Remote is chosen using ARAC methodology of calculating sum of all remaining failures. This is more conservative than the existing standards, but has a reduced scope. Unlike the existing means of compliance, it does not apply to active – active failure combinations. Eliminating the active – active failure conditions from the specific risk criteria does not impact the over all safety benefits of the analysis because the conditions of concerned are covered under the average risk criteria of FAR/CS 25.671(c)(1) & (c)(2) and FAR/CS 25.1309(b)(1). With regard to residual risk the ASAWG was only concerned with situations in which the airplane could be operating one failure away from a Catastrophe for multiple flights.

Existing means of compliance for flight controls only consider residual risk for single latent failures. These practices do not apply residual risk assuming the presence of multiple latent failures. The ASAWG has kept to this philosophy in regards to quantitative residual criteria. As a result residual risk has the most impact on dual failures. Therefore the ASAWG has limited the residual risk application to dual failure combinations.

The ASAWG new limit latent regulation applies to individual latent failures rather than the sum of latent failures associated with a single active failure. The impact of 1/1000 on exposure times associated with multiple latent failure combinations was considered not significant. Therefore the limit latency requirement is also limited to dual failure combinations.

To be consistent with average risk calculation model the ASAWG decided not to adopt the maximum dormant model for latent failures. This is not a significant issue because this did not represent an order of magnitude change in inspection intervals. Further the applicant would not run two different types of fault tree calculations for latency. Therefore the application of maximum dormant model could effectively change fault trees from an average risk calculation to a maximum risk calculation by practice if not by requirement.

The change to FAR/CS 25.671(c)(3)(iii) affects dual failures where the active failure of the jam (normally encountered) is alleviated by a device that can be latent for more than one flight. The change is consistent with how other single failure plus latent failure combinations are addressed by the ASAWG. It is also consistent with the scope of the original rule.

- Replace FAR25.901(c) with:

(c) The powerplant installation must comply with FAR25.1309(b), except that the effects of the following need not comply with FAR25.1309(b):

(i) Engine case burn through or rupture;

(ii) Uncontained engine rotor failure; and

(iii) Propeller debris release.

<u>Introduce AC/AMC 25.901:</u>

C:\Safety\TAEIG WG
SR Meet 12\Latent\2!

<u>Rationale:</u>

It was decided that FAR25.901 does not have latent specific risk criteria included in the rule; however, there is policy that require the review of latent related specific risk; therefore, a recommended change is provided. In addition, upon application of the proposed AC/ACJ 25.901 (see attached) compliance to the remote requirements of the proposed 25.1309(b)(4) has been included.

ASAWG Recommends adoption of the related ARAC PPIHWG and SDAHWG Recommendations as modified by the ASAWG recommendations made elsewhere in this report. Adoption of the ASAWG recommendations regarding FAR/CS 25.1309 would result in a level of safety for powerplant systems at least equivalent to that provided by the current interpretation of FAR/CS 25.901(c) while facilitating a more consistent and objective means of demonstrating compliance. For example, the "no single failure" requirement would be covered by the revision to FAR/CS 25.1309(b) proposed by ARAC SDAHWG and clarified by ASAWG recommendations. The avoidance of "latent plus one" failure conditions would be covered by the ASAWG recommendation to eliminate significant latent failures wherever practical. In addition the ASAWG recommendation would provide a more objective and hence consistent maximum acceptable residual risk when operating one failure away from a catastrophe.

- Replace FAR/CS 25.933(a)(1) with:

(a) For turbojet reversing systems

(1) Each system intended for ground operation only must be designed so that either—

(i) The airplane can be shown to be capable of continued safe flight and landing during and after any thrust reversal in flight; or

(ii) It can be demonstrated that inflight thrust reversal complies with FAR25.1309(b)(1) & FAR25.1309(b)(4). ~~*is extremely improbable and does not result from a single failure or malfunction.*~~

<u>Introduce AC/AMC 25.933:</u>

Replace Sections 8.b.2 and 8.b.3 of the attached TAEIG PPIHWG AC 25.933X with a Section 8.b.2 as follows:

In accordance with Arsenal Draft of AC/AMC 25.1309, Section 9.b.(6), whenever practical, latent failures should be avoided. It has traditionally been deemed practical to avoid catastrophic in-flight thrust reversal failure conditions due to any "single latent plus single active" (a.k.a "latent plus one") failure combination.

C:\Safety\TAEIG WG\
SR Meet 12\Latent\T/

Rationale:

A change to FAR/CS 25.933(a)(1)(ii) was recommended because the rule combined with recent policy implies latent specific risk criteria should be applied to thrust reversers. This policy is based on earlier ARAC recommendations currently being used and requires the review of latent related specific risk. Therefore, the introduction of the ARAC PPIHWG version of AC/ACJ 25.933 with the deletion of Sections 8.b.2 and 8.b.3 was provided to ensure consistency across the Industry and systems.

ASAWG Recommends adoption of the related ARAC PPIHWG and SDAHWG Recommendations as modified by the ASAWG recommendations made elsewhere in this report. Adoption of the ASAWG recommendations regarding FAR/CS 25.1309 would result in a level of safety for powerplant systems at least equivalent to that provided by the current interpretation of FAR/CS 25.933(a)(1)(ii) while facilitating a more consistent and objective means of demonstrating compliance. For example, the “no single failure” requirement would be covered by the revision to FAR/CS 25.1309(b) proposed by ARAC SDAHWG and clarified by ASAWG recommendations. The avoidance of “latent plus one” failure conditions would be covered by the ASAWG recommendation to eliminate significant latent failures wherever practical. In addition the ASAWG recommendation would provide a more objective and hence consistent maximum acceptable residual risk when operating one failure away from a catastrophe.

- Change to FAR/CS 25.981(a)(3):

(a) No ignition source may be present at each point in the fuel tank or fuel tank system where catastrophic failure could occur due to ignition of fuel or vapors. This must be shown by:

(3) Demonstrating compliance with FAR25.1309(b)(1) & FAR25.1309(b)(4). ~~could not result from each single failure, from each single failure in combination with each latent failure condition not shown to be extremely remote, and from all combinations of failures not shown to be extremely improbable.~~ The effects of manufacturing variability, aging, wear, corrosion, and likely damage must be considered.

- Changes to AC/AMC 25.981-1/2:

The ASAWG did not have the experience to recommend changes to AC/AMC 25.981-1/2 but recognize the need to update these to at least result in more realistic consideration of the conditional probability that the presence of a potential ignition source will result in a catastrophic fuel tank explosion.

Rationale:

This regulation has been the discussion of many certification activities since it was adopted and in many cases the criteria could not be fully satisfied requiring exemptions of the rule. In addition, this rule is not harmonized between the FAA and EASA resulting in further disconnects between manufacturers. Therefore, all specific risk criteria have been eliminated from the rule and it is recommended that a similar task be done in the guidance.

However, it was agreed within the group that there was not adequate knowledge in the ASAWG of the criteria that went into the definitions related to a potential ignition source and how probabilities are related to these. The requirements provided in FAR/CS 25.1309(b) and the guidance of Arsenal Draft of AC/AMC 25.1309 are considered to provide adequate coverage for latent failure conditions.

6.4.1.3 Benefits of the Recommendations

ASAWG has made trade offs between invalidating existing designs, increasing the analytical burden and being conservative when deriving the recommended airplane level specific risk criteria. The key benefit Industry saw after several years of review and discussion was harmonization and consistency across all systems and between various regulation bodies. Unlike previous working groups that were tasked to respond to a specific event or threat that had occurred, this effort is more of a harmonization across the aircraft and regulatory bodies. Therefore, the identification of potential measurable safety benefits was not identified.

<u>The proposed changes:</u>

- Eliminates the inconsistent application of various residual risk criteria via IPs and CRIs ranging from 1E-3 to 1E-6. Manufacturers and Regulators alike spend excessive time early in the airplane development cycle negotiating these based on their specific airplane and system designs. The cost related to this was impractical for the manufacturers and regulators to quantify but involve both non-recurring labor cost and recurring equipment costs.
- Increases safety by providing applicants and regulators clear guidance that can be applied consistently across systems.
- Avoids non-standardized system safety assessments across various critical systems making it hard to properly evaluate at the aircraft level, which could cause conflicting interpretations for conducting system safety assessments in aircraft certification programs, Currently, manufacturers performing aircraft level analysis or highly integrated system level analysis based on the worst case criteria. This has the potential to add cost and complexity to the systems. The actual value of this savings could not be quantified when looking at existing systems.
- Provides for an acceptable level of safety across all systems and applications. This is intended to be adequate for coverage of all systems related to specific risk and minimize the generation of new rules, special conditions, IPs, CRIs, etc..., in the future.

6.4.1.4 Costs Impacts of the Recommendations

All the members of the ASAWG were requested to provide a Cost and Benefits (C/B) analysis in 2010 US dollars based on the proposed changes. The electronic suppliers abstained from the process on the basis they respond to the airframer's requirements and any cost would be shown at that level. The engine suppliers did not provide any C/B analysis but one did provide a dissenting opinion (see Section 6.4.1.6) that was later addressed and closed with all the engine manufacturers supporting the proposal.

When reviewing the costs associated with the changes, manufacturers reviewed existing certified aircraft and determined what system or maintenance interval would be changed through the review of already released fault trees. The cost provided below is the cost to bring that airplane up to the proposed changes. Change cost was considered conservative but appropriate because many times manufacturers try to carry system designs forward to new models.

Likewise, potential savings that could be realized in systems that were driven by the more stringent requirements that got applied on an applicant by applicant basis or were the existing system level requirements have actually been relaxed was considered minimal. The rationale for this position was again the practice of the manufacturers not to make changes to already certified designs that could still be applied to a new product.

The cost benefit analysis performed by the various airframe members of the Working Group could be categorized into three unique responses:

- Large aircraft over 100,000 lbs
- New Business FBW aircraft
- Smaller Business Jet aircraft

- <u>Large aircraft over 100,000lbs:</u>

  Airbus, Boeing and Embraer are the airframers that make up this sub-group. In all cases they identified potential impact to operations and/or the design of the aircraft. There were two methods recognized to resolve any impacts caused by the changes recommended. One was to change the design practices that were previously applied to existing aircraft resulting in potential increase in the cost of the aircraft and the other was to change maintenance intervals thus impacting the operational cost of the aircraft. These two methods are not exclusive of one another and because design philosophies vary from one airframer to another they will not be consistent from one another. However, there was a definitive resultant impact that can be derived from the three C/B analysis provided, they are:

  - Design Impacts:
    - Total Non-Recurring Cost per Model range from $13M to $20M.
    - Total Recurring Cost per Airplane range from $34K to $70K.
  - Operational Impacts:

- Added Maintenance Cost per Airplane per year is approximately $800.
- Added Fuel Burn per Airplane per year range from $2K to $3K.

The detail cost analysis worksheets that went into this summary are located in Appendix A section 6.4.5.1.

- New FBW aircraft operating mainly under Part 91 and 135:

Dassault and Gulfstream provided the C/B analysis for this sub-group. For these two manufacturers, the only cost impact identified was a one time nonrecurring cost to update the policies and procedures to include automated software used to perform the analysis. Dassault identified this cost to be on the order of $100,000.

The detail cost analysis worksheets that went into this summary are located in Appendix A section 6.4.5.2.

- Smaller aircraft operating mainly under Part 91 and 135:

There are several manufactures that make up the working group that have aircraft in this category; however, only one identified potential cost they may incur in future aircraft development. Their costs were:

- Design Impacts:
  - Total Non-Recurring Cost per Model was approximately $9M.
  - Total Recurring Cost per Airplane was approximately $1.6M.
- Operational Impacts:
  - Added Maintenance Cost per Airplane per year is approximately $25K.
  - Added Fuel Burn per Airplane per year is approximately $60K.

The detail cost analysis worksheets that went into this summary are located in Appendix A section 6.4.5.23.

6.4.1.5 Alternatives considered and why they weren't chosen

The alternative of not making any of the changes described in section 6.4.1.2 was considered at each step of the review and recommendation development process of this tasking. In each case, the pros and cons were identified and recorded in the report under Task 2 and Task 3. The final Latent Task 4 change recommendation was established by taking into account the comments from all organizations as received during Task 4. There were only two areas that were identified in Task 3 for potential change that did not finally result in a change recommendation. They were FAR/CS 25.783 and FAR/CS 25.1709.

- No change to FAR/CS 25.783:

Rationale:

As of today, FAR/CS 25.783 does not have latent specific risk criteria included in the rule. Though there was numerous safety requirements, both quantitative and qualitative, for fuselage doors, the Working Group did not see any peculiar requirements other than employing the average risk and no single failure criteria of FAR/CS 25.1309. It was also recognized by the Working Group, that applying specific average risk or no single failure safety design criteria to specific features within a specific functional area was appropriate. Section 25.783 requires that "Each door that could be a hazard if it unlatches must be designed so that unlatching during pressurized and unpressurized flight from the fully closed, latched, and locked condition is extremely improbable." In addition, the failure criteria in 25.1309(b)(4) would apply to any door whose opening would be catastrophic.

- No change to FAR/CS 25.1709:

  Rationale:

  As of today FAR/CS 25.1709 does not have latent specific risk criteria included in the rule.

  The FAR/CS 25.1709 is new and was never applied up to now. ASAWG sees the need for getting experience from first applications before any change should be foreseen.

  The AC/AMC 25.1709 is giving means of compliance for the FAR/CS 25.1709. These means of compliance are giving quite detailed recommendation how to comply with FAR/CS 25.1709 in a qualitative approach, but there is no recommendation to comply in case of quantitative aspects. Any future foreseen change for the FAR/CS 25.1709 should lead also to detailed changes for the AC/AMC 25.1709 to make possible a consistent interpretation regarding appropriate means of compliance.

6.4.1.6 Dissenting Opinion and Discussion

6.4.1.6.1 Cessna

Cessna submitted the following dissenting opinion:

Cessna has the unique position of being the only aircraft OEM to certify three all new business jets using the process spelled out in SAE ARP 4761 as a means of showing compliance to 1309. At the same time, Cessna was the only aircraft OEM to vote NO on the latent section on the Task 4 report. The purpose of this dissenting opinion is to explain why.

It has not been demonstrated to Cessna that the following proposed AC and rule change results in a net safety increase or that it can be supported by a cost benefits analysis:

"25.1309 b(4) For each catastrophic failure condition that results from two failures, either of which is latent for more than one flight, it must be shown that -

(i) Given any single latent failure has occurred, the combined probability per flight hour of catastrophe due to any subsequent single failure is remote; and

(ii) The probability of occurrence of the latent failure is on the order of 1/1000 or less."

Typical fault trees today used to show compliance to 1309 contain well over 1000 basic events; several hundred of those basic events may be latent. While the proposed AC changes do "bound the problem" and limits the "what if's" to be considered, the applicant is forced to analyze and document the "bounded" cut sets. If the AC "bounds the problem" as stated in the Task 4 report, then typically there are 100 cut sets of interest for each catastrophic functional failure condition. Since each all new aircraft has close to 100 catastrophic functional failure conditions, the proposed process results in ~10,000 cases to look at (100 cut sets times ~100 functional failure conditions). While the fault tree program generates these, the cut sets have to be exported into another program (i.e. spreadsheet) and additional analysis has to be generated and documented.

Of course, as stated in the report "An alternative but more conservative method would be to rerun the fault tree probability calculation assuming for each model rerun that a different latent basic event had failed". It is clear to Cessna, that no applicant will run and document ~10,000 additional fault trees.

In the spring of 2009, Cessna ran a test case to evaluate the costs and benefits of this activity. The aircraft used for this evaluation was Cessna's most recent all new part 25 aircraft. The process this aircraft was evaluated against was the leading contender the ASAWG group was proposing. Cessna's estimate is that it would take close to 2 million dollars to complete and document the analysis for an all new business jet aircraft. The "final" method published in the ASAWG task 4 report is 3 to 4 times more "work intensive" than what was run in the 2009 trial. Our "final" estimate to conduct this analysis on a part 25 business jet is 6 to 8 million dollars. For Cessna, this is about half the retail cost of a new part 25 aircraft.

It should be pointed out that all 110 catastrophic functional failure conditions were examined and none of them were flagged as being "non compliant" to the proposed rule. Cessna's position is that this is an additional cost without a proportional safety benefit for part 25 business jets. Cessna can not support spending an additional 6 to 8 million dollars on certification when the result of the additional cost does not provide any safety benefit. Cessna is not taking this position because it has a tried and true design that would no longer be compliant. Cessna is taking this position because the documentation that Cessna would have to produce to show compliance is not supported by a cost benefits analysis and outweighs any gain to be had by the "harmonization and consistency" the Task 4 report proposes.

In some non-ETOPS two engine applications, it should be pointed out that if a latent failure causes an in flight shut down of an engine, the other engine will not be able to meet the remote criteria of 1e-5. Most non-ETOPS part 25 engines have a failure rate close to 2~3e-5 per flight hour. When this is summed with the other residual risks, it is clear that the design will not support the requirement. This will introduce redundancy (a third engine) or system complexity (monitoring that has to be better than 2~3e-5). This will likely have an adverse effect on safety since most accidents are not caused by system failures, but by the crew not responding to a system fault correctly.

Finally, the ASAWG group failed to address the case where one latent combines with more than one active in more than one catastrophic functional failure condition. To demonstrate, let us assume that the same latent appears in a landing gear and flight controls catastrophic functional failure condition cut set listing that needs to be evaluated. In this example, the report does not address what the applicant would do, and it is open to interpretation. Since this is not explicitly addressed in the report, proposed preamble or proposed AC, Cessna is very concerned that the regulators would force the applicant to show that the total residual risk summed across all the functional failure conditions where the latent occurs is remote. In this case, our cost estimate would increase by 2 million to between 8 and 10 million dollars, or half the retail cost of a part 25 business jet, without a safety benefit.

<u>ASAWG disposition of Cessna Dissenting opinion:</u>

This response to Cessna's dissenting opinion is not a point by point rebuttal but more of a philosophical and general industry response.

First, the comment that Cessna is the only "aircraft OEM to certify three all new business jets using process spelled out in SAE ARP 4761 as a means of showing compliance to 1309." is not relevant and is misleading. First, both Airbus and Dassault have both certified Part 25 aircraft not only to the tools called out in ARP4761 but to the system engineering process called out in ARP4754 and the "diamond" version of AC/AMC 25.1309. In addition, both Boeing and Gulfstream have mature Part 25 aircraft certification programs ongoing with the FAA using both ARP4761 and ARP4754 modified to reflect the latest changes being made in Revision A of ARP4754 and CS25.1309. Finally, the focus of the ASAWG efforts have been harmonization from one system requirement to another as it relates to the aircraft system level requirements of 14CFR 25.1309. The fact that specific and unique safety analysis over and above the requirements of 25.1309 and AC 25.1309-1A must be performed for systems such as flight controls, thrust reversers, engines etc. is not addressed by Cessna.

In the cost analysis reviews done by all the current airframe manufacturers developing Part 25 aircraft it was recognized that there would be potential increase in scope and work related mainly avionics systems. However, because of the increasing integration and complexity of avionics support of flight controls, engine control, thrust reverser deployment, etc. the potential increase was acceptable provided the criteria established was completely implemented such that no existing or new system peculiar specific risk criteria for latent conditions would be specified on new projects.

Finally, to respond to Cessna's two concerns about implementation of the recommended rule. First, the engine example was reviewed in great detail with all four of the engine manufacturers expressing their concerns. The discussion on GE's dissenting opinions is examples of these discussions of concerns and how they were resolved and dealt with. The qualitative term "remote" was used in the proposed 14CFR 25.1309(b)(4)(i) in lieu of a quantitative term such as less than 1E-5 to permit the OEMs and regulators to use the historical application of "remote" to mean "of-the-order-of" or "on-the-order-of" thus recognizing the potential for state of the art engines satisfying the requirement by being 2 or 3 E-5.

Cessna's final concern of a latent failure condition in a functional system that supports several aircraft systems that have independent catastrophic conditions was raised during Group discussions and the residual risk criteria from 25.1309(b)(4) is clearly seen as limited to one failure condition and has not to be applied across several failure conditions, where the same latent failure occurs. The proposed 25.1309(b)(4) starts therefore with "For each catastrophic failure ....".

For the reasons stated above, the ASAWG still sees merit in supporting the proposed changes to address latent specific risk in lieu of the concerns and cost that Cessna has identified.

6.4.1.6.2 EASA

<u>EASA submitted the following dissenting opinion:</u>

Ref: Section 6.4.1 of the draft ASAWG Final report produced after Cologne Meeting

The following documents EASA dissenting opinion on one particular aspect of the latent failure proposal regarding modification of 25.933(a)(ii) and associated advisory material.

This must be understood in the context of CS-25 updating following the recommendations from the ASAWG. It also relates to the particular situation of CS-25 (compared to FAR 25) where many of the previous recommendations coming from ARAC SD&A HWG and PPIHWG have already be incorporated, notably the 25.1309 one and the associated AC/AMC “Diamond” version as proposed by the SD&A HWG, 25.901 and 25.933 as proposed by the PPIHWG.

EASA is supportive of the concept of having an aircraft level harmonized approach for dealing with specific risk/latent failures.

As part of the latent failure task package, the ASAWG group proposal introduces a new 25.1309(b)(4) that specifies acceptable criteria for limiting latency/residual risk for a catastrophic failure condition resulting from the specific combination of two failures either of which can be latent for more than one flight.

The other aspects like minimization of latent failures, elimination of those latent failures whenever judged practical and considerations of multiple latents in combination with a single active have been included in the AC, but not formally covered in the rule following the deliberations of the Working Group.

Proposed revision to 25.933(a)(1)(ii) makes direct reference to compliance with 25.1309(b)(1) & (b)(4) for in-flight thrust reversal when “reliability option” is chosen. The AC/AMC FARFAR 8(b)(2) and 8(b)(3) “specific risk” criteria are proposed to be deleted and reference is made to AC/AMC 25.1309 provisions that deal with 25.1309(b)(4) compliance.

As formally proposed, the revision to 25.933(a)(1)(ii) could be seen as a reduction of safety compared to what is currently achieved by compliance with CS 25.933(a)(1)(ii). This is mainly driven by the fact that the proposed 25.1309(b)(4) only addresses the combination of two failures, either of which could be latent.

Existing FAR 8(b)(2) would not allow for the configuration regulated through 25.1309(b)(4) (there should not be a combination of one active and one latent that results in in-flight thrust reversal). Existing FAR 8(b)(3) limits latency exposure for cases of three failures or more. Both paragraphs relate to currently accepted practices that have been shown to be practical and also introduced to cover adverse service experience.

Based on the currently proposed 25.1309(b)(4), provisions of the existing AMC FARFAR 8(b)(2) and 8(b)(3) should be kept as providing a clear reference of currently accepted practices for thrust reversers.

Other options may be available in case a more robust 25.1309(b)(4) is introduced.

<u>ASAWG disposition of EASA Dissenting opinion:</u>

When developing SR criteria and methodologies it was recognized by the ASAWG that the most conservative standard would not necessarily be adopted. Each area of design: Flight controls, TRs, etc had what was thought to be an acceptable standard and means of compliance for critical failure conditions. To state that the level of safety for 25.933 is unacceptably compromised implies that other existing standards today are unsafe. This is not a view shared by those other disciplines.

Dissent relates to acceptable standard, reference T/Rs. See response to FAA OPINION #2.

6.4.1.6.3 FAA

<u>FAA dissenting opinion and ASAWG disposition:</u>

<u>OPINION #1:</u>

The FAA has concerns about the term “on the order of” directly being in the rule. It makes little sense to define a specific numerical threshold and then intentionally make it vague. This will lead to the obvious question: what does “on the order of” mean numerically? The example in the Appendix clearly shows the intent is not to exceed the 1/1000 criterion, except in rare cases whose rationale can be presented as illustrated in the last sentence of this paragraph.

In lieu of using “on the order of,” the FAA would prefer to preface the 25.1309(b)(4)(ii) requirement with “Unless otherwise approved by the authority.” This would achieve the same objective, which is flexibility in rare cases.

<u>ASAWG disposition to OPINION #1:</u>

There was a lot of discussion over 3 years in the Group with the use of qualitative terms (e.g. Probable, Improbable, Remote, Extremely Remote, and Extremely Improbable) in lieu of the quantitative terms (see the preamble in Section 6.4.1 for more discussion on this). However, the use of qualitative term "probable" to mean "of-the-order-of 1E-3 or less" was not acceptable because the term "probable" is used several ways so the actual definition used in AC/AMJ 25.1309 was used as the requirement. The term "of-the-order-of" has been used in the Industry since Amendment 25-23 was released to 14CFR25 in 1970.

OPINION #2:

As stated at meeting #14 in Cologne, we agree with this AC material that "whenever practical, these latent failures should be avoided.", but we are concerned this will not be enforceable and is "rulemaking by AC" given the intent of the AC material. Moreover, EASA and FAA both conveyed to the WG that without a means to back this up, the level of safety provided by the ARAC 25.933 recommendation could be unacceptably compromised. We re-iterate the necessity and importance of having a rule requiring elimination or minimization of significant latent failures unless impractical.

ASAWG disposition to OPINION #2:

The first part of dissent relates to enforcement of minimization criteria. The application of fail safe design philosophy as well as minimization of latency has been enforced by Industry for a number of years though it is not a rule. The rationale by the Group was to develop a minimum quantitative criterion that could be applied to all systems. The establishment of this quantitative requirement was in response to Industry's desires to have a known boundary that can be black and white and that cannot be passed. Minimization statements are too open but are recognized as good design practices and one that Industry implements. This is the reason for not putting an undefined term in the regulation; the minimum requirement is in the regulation.

The second part of dissent relates to acceptable standard. When developing SR criteria and methodologies it was recognized that ASAWG would not necessarily adopt the most conservative standard. Each area of design: Flight controls, TRs, etc had what was thought to be an acceptable standard and means of compliance for critical failure conditions. To state that the level of safety for 25.933 is unacceptably compromised implies that other existing standards that do not employ the same criteria as the thrust reversers are not as safe as the thrust reversers. This is not a view shared by those other disciplines and why combinations of several of these standards were used to derive the final recommendation.

OPINION #3:

The FAA continues to believe that revising AC 25.629-1A should only be done after consulting with the flutter community.

We therefore ask that each OEM represented on the ASAWG contact their flutter experts and explain the ASAWG proposed changes to 25.671 and 25.1309 and associated guidance, and the proposed solution for AC 25.629. The ASAWG-proposed change to AC 25.629 should be discussed as well as the FAA proposal, shown below. We also ask that those flutter experts, or appropriate representatives, then contact Todd Martin (todd.martin@faa.gov) to provide their opinion on changes to AC 25.629.

FAA-proposal for AC 25.629-1A, Section 5.c.(3)(c):

"Any damage or failure conditions considered under FARFAR 25.571, 25.631, 25.671, and 25.1309.

The actuation system minimum requirements should also be continuously met after any combination of failures not shown to be extremely improbable (occurrence less than 10-9 per flight hour). However, certain combinations of failures, such as dual electric or dual hydraulic system failures, or any single failure in combination with certain electric or hydraulic system failures, are not normally considered extremely improbable based on service history. Therefore, a qualitative assessment should also be conducted in addition to the quantitative assessment. The latent failure criteria of FAR 25.1309(b)(4) must also be considered. The reliability assessment should be part of the substantiation documentation."

<u>ASAWG disposition to OPINION #3</u>:

The concern that the flutter communities are not involved is not understood by the ASAWG. The ASAWG Industry members have been coordinating the proposed changes with the various functional organizations within their respective Companies since the beginning and is the reason for highlighting in the case of flutter 14CFR 25.629 and AC 25.629-1A for change.

The FAA proposal seems to want to retain specific risk criteria for active – active failure combinations, i.e. certain active – active failures that are not extremely improbable based on service history. This may be problematic if it is interpreted that ALL single failures in combination with certain electric or hydraulic system failures are not extremely improbable. It is far better to follow the 1309 AC process in making this determination. It is consistent with generating a standard means of compliance which was one of the primary objectives of the ASAWG.

<u>OPINION #4:</u>

Firstly, the proposed wording for (iii) developed in Cologne would need to be modified, as shown below, to be consistent with the ASAWG intent and the proposed AC 25.671 changes.

In the presence of a jam considered under this sub-paragraph, any single latent failure state that could prevent continued safe flight and landing when combined with the jam must satisfy the specific risk criteria of FAR/CS 25.1309(b)(4)(ii).

Secondly, even with this change, the FAA does not agree to change the FCHWG recommendation on 25.671(c)(3) for the following reasons:

(1) While the FCHWG proposal was deliberated exhaustively by numerous organizations and disciplines, there's been no such deliberation on the ASAWG proposal as it was developed near the end of the Cologne meeting;

(2) the FCHWG proposal specifically addresses jams, which are a unique phenomena for which unique criteria are appropriate - the 1/1000 criterion would essentially apply to jam alleviation systems; (3) it would be more clear to simply state the requirement in 25.671(c)(3) rather than point to a subparagraph of 25.1309.

The FAA will deliberate further on both the FCHWG and ASAWG proposals for 25.671(c)(3), and will work with the authorities to develop the final harmonized proposal.

ASAWG disposition to OPINION #4:

The suggested change would limit the scope of latent specific risk to only the specific risk portion and not include residual risk. Per the definition in the FCHWG AC jams are considered a type of failure and include jam valves, etc; therefore, this condition should not have peculiar criteria. For the jam conditions resultant from external events then the ASAWG does concur with the FAA's response in those conditions are "unique phenomena" and should be covered under the proposed AC/AMJ 25.1309 paragraph 11g or even in a peculiar criteria under 25.671 and can be appropriately handled by the FCHWG. As stated before, the intent is not to have specific application for one system but not another so the general reference to FAR/CS 25.1309(b)(4) and not just FAR/CS 25.1309(b)(4)(ii).

The statement that the CFR 25.671 was not discussed exhaustively does not seem relevant. The specific risk criteria have been discussed exhaustively and therefore the only relevant question would seem to be are the SR criteria applicable to this rule. Is it a latent plus one failure condition? It is not clear whether the second point is implying that 1/1000 criteria should be applied at the system level rather than the basic event level. However this would be inconsistent with ASAWG objectives.

6.4.1.6.4 Garmin

Garmin submitted the following dissenting opinion:

OPINION #1:

Section 6.4.1 Last paragraph:

Comment: Should not the comma after the word "yet" be after the word "aircraft"?

Dissent: If the change is not significant but some additional rules not in the existing airplane certification basis are determined necessary for the STC has not the applicant got a new certification basis for those aircraft affected by the STC? Garmin would say yes and per this wording would have to pick up the SR rule.

Recommendation: Finally, because these changes provide no measurable safety reduction at the aircraft, yet include the general system requirements provided in FAR/CS 25.1309 that are applicable across all systems, they should not be applied retroactively. For changes to existing TC/STC, the application of this proposed amendment of FAR/CS 25.1309 and associated guidance should only be required for those changes determined to be significant as defined by FAR/CS 21.101(b).

ASAWG disposition to OPINION #1:

This was the intent of this paragraph. It is the understanding of the ASAWG that when an applicant decides to step up to new regulations and/or guidance when not required to per 14CFR21.101(b) that these type of specific certification basis issues would be discussed and resolved as part of the applicants submittal of the change as not significant.

OPINION #2:

Section 6.4.1.1.1 Add to Arsenal Draft of AC/AMC 25.1309, Section 9.b.(6):

Dissent: Section 9.b.(6) of the proposed AC can be interpreted to be more severe than the quantitative requirements of the regulation. As written, even if the applicant's design is triple redundant or better (e.g. 2 latents plus an active), it may still not be viewed as sufficient even though all aspects of the rule had been satisfied. What is sufficient seems to be is subjective and unbounded other than the E-12 statement. During the final stages of the design substantiation the regulatory authorities could review the SSA and in theory could request additional redundancy. Since adequacy is subjective and unbounded, the application may differ from ACO to ACO. This falls short of the committee objective to standardize the treatment of specific risk management.

Recommendation: It is recommended that the 25.1309 (b) (4) rule or AC 25.1309 guidance be revised to limit the addition of redundancy to dual failure conditions where a latent failure is present for more than one flight. This is still consistent with the guidance for 25.629 and 25.933. Given that CFR 25.629, 25.933 and 25.981 together addresses no more than three catastrophic failure conditions out of the total that has to be evaluated by all rules such as 25.671 and 25.1309, this recommendation does not deviate from the ASAWG objective of adopting a consistent certification standard. The quantitative requirements of 25.981 were not considered warranted by the ASAWG when compared to current evaluation performed for the majority of critical systems.

ASAWG disposition to OPINION #2:

The criteria developed in the proposed section of AC/AMC 25.1309 Section 9(b)(6) was derived from the current AC/AMJ 25.1309 that EASA has implemented over the past several years and on two already certified aircraft. Garmin's position is the opposite of the regulators concern of the guidance not going far enough and not being in the regulation. The ASAWG felt this qualitative approach as implemented by EASA over the past several years has worked with minimal concern. The need to understand latent failure modes that are involved in a catastrophic condition is just good design practices and the proposal provided by the ASAWG is no more than an appropriate design organization will do internally.

6.4.1.6.5 General Electric

GE dissenting opinion and ASAWG disposition:

C:\Safety\TAEIG WG
Final Report\Latent\G

The following is ASAWG's response to GE's dissenting opinion with GE's position in italics and green color. Since the development of this response, GE has reviewed the proposal and discussed with the other engine manufacturers on the ASAWG. GE currently concurs, that modern engine designs have good latency and residual risk levels on a fleet average basis and manage to appropriate deterioration levels. However, GE still has some concerns with the actual implementation, given that the specific risk of concern definition is too broad, potentially driving system complexity or maintenance action for new certifications that could be overly conservative and impact reliability more than they improve safety.

- <u>Certification Inconsistencies</u>

“The primary ASAWG position has been that specific risk work was to address inconsistencies in the certification process, and was not addressing known accidents that could have been avoided with specific risk. While GE agrees that the FAA and other authorities should treat all applicants consistently, we disagree that consistency should require the exact same methodology to be used for mechanical and electronic systems, as an example. Mechanical systems with well understood revenue service experience have been safely certified to differing requirements than more complicated electronic systems.”

ASAWG was specifically restricted from considering the role of specific risk in historical accidents. We were tasked to harmonize the specific risk analysis methods and criteria across all aircraft system. However, it is recognized that, while the criteria should be the same regardless of the technology utilized, there will be differences in acceptable methodologies as a function of the technology, novelty and complexity. These accommodations are already inherent within the AC25.1309 guidance.

- <u>Golden Rule Numbers</u>

“It was stated that specific risk changes were not intended to change the < 1E-9 level for average fleet risk. From the beginning, definitions for “specific risk “and “specific risk of concern” were not accurate. As a result, the latency and residual risk numbers would drive the fleet average risk lower than 1E-10. GE’s primary issue is with the numerical values defined in what was referred to as the “Golden Rules. The minimum latency should have been no lower than 1E-2, instead of 1E-3. The minimum residual risk should have been 1E-4, instead of 1E-5.

For example, the ETOPS upper limit of 0.02 IFSDs per 1000 flight hours that the industry has been safely managing to, translates to a potential residual risk of 2E-5 when left with one engine. An engine just meeting ETOPS criteria, IFSD rate of 5E-5 to 2E-5/hour, would fail the golden rule on residual risk. This is a simple example that illustrates how the more restrictive specific risk numbers would drive the fleet average risk lower than 1E-10, and preclude the use of design architectures which have already demonstrated their safety over decades.”

ASAWG believes that GE provides no relevant evidence to compel ASAWG to increase the limiting latency or residual risk criteria.

The ETOPS residual risk example is an active-active failure case specifically covered elsewhere in our report, but to which FAR25.1309(b)(4) does not apply.

Furthermore, the quoted ETOPS criteria is not really a comparable residual risk criteria, but rather a threshold indicating sufficient design and operational maturity to enter ETOPS. However, the authorities still require any potentially endemic cause of IFSD be fixed to further reduce (i.e. minimize) the IFSD rate. This in turn has resulted in engine run reliabilities much better than these thresholds in most cases.

For further explanation of the relevant applicability of the "Golden Rule Numbers", see our response to your "Cost Benefit Analysis" comments.

- Specific Risk of Concern

"GE also has issues with the definitions associated with several terms used by the ASAWG. To define "specific risk of concern" as "the risk is greater than the average probability criteria provided in AC 25.1309 Arsenal for hazardous and catastrophic failure conditions" is incorrect since much of the 3 sigma risk deviation above the average occurs frequently and is no problem. By definition, half of any fleet will have risk above average. The specific risk of concern should be limited to particular conditions that exceed 1E-4. Again, this is a simple example that illustrates how the definition of specific risk of concern would drive the fleet the average risk lower than 1E-10."

These definitions were developed to help ASAWG "scope" the task at hand. While we would agree that what is truly a specific risk of concern is one that does not meet the proposed FAR25.1309(b)(4) criteria, that was not the purpose of this term at the time it was defined. ASAWG sees nothing but disadvantages to re-writing history at this point.

- Specific Risk Cause and Affect

"GE believes that the lack of identified accidents with root cause factors related to specific risk, supports the position that the real risk is a failure to model the unknown or unsuspected cause factors, or to correctly classify the severity of an effect, which out weighs specific risk concerns. Setting challenging latent and residual risk numbers will not protect against the failure to model what is unknown or not suspected to happen. FMECA models only model what is known."

ASAWG doesn't necessarily disagree that there may be more value added in improving other aspects of safety analyses. However, that fact is not relevant to completion of this tasking. Furthermore, we were specifically restricted from considering the role of specific risk in historical accidents. We were tasked to harmonize the specific risk analysis methods and criteria across all aircraft system. Consequently ASAWG does not intend to change our recommendations due to this GE Opinion.

- <u>Cost Benefit Analysis</u>

"Finally, a cost-benefit analysis would show the industry driving very significant costs into design, manufacture, and maintenance of engines with no measurable safety benefit and a probable loss in system reliability if additional redundancy or monitoring is added. Again, the ASAWG "certification consistency" approach, with no identifiable safety benefit, has no cost benefit to off set the increased cost of certification, increased maintenance cost, and an increase in the disruptions to revenue service.

As noted above, the Golden Rules could prevent certification of any future twin-engine aircraft. This would introduce very significant costs to operators. Furthermore, certification will cost more due to the increased analysis of systems that do not pass the 1E-12 screening filter. For example, any progressive deterioration or loss of margin that might, in an envelope corner point with a thrust increase to Max. Continuous power, could lead to a second IFSD. An aerodynamic loss of stall margin, a loss of EGT margin, reduced thrust due to an air leak which opens up more under high power, a cracked blade which propagates to separation under high thrust, an electrical connection which gets more vibration at higher power, giving an intermittent fault, or a hot duct leak onto a fire detector are examples of latent conditions. Use of the Golden Rules would require either a proof that the hypothetical failure could never result in an IFSD, or significantly more analysis and monitoring or CMRs to limit their probability/latency period. Conservatively, the added design and analysis could add several million dollars to a new engine program.

With the addition of any new redundant or system monitoring features to limit the maintenance impact, comes a reduction in system reliability. Therefore, whether an operator pays for additional system complication or elects to increase maintenance or reduce maintenance intervals, the economic impact drives millions of dollars of cost to the airline operators.

As an engine manufacturer, it is difficult to see where there is any cost benefit to the current certification process."

ASAWG is still working on the airplane level cost/benefit analysis, but with (and perhaps even without) being able to consider the role of specific risk in historical accidents, we agree that it will be very difficult to show a net dollar benefit. Consequently the quantitative costs will have to be assessed by both ASAWG and TAEIG against various noted qualitative benefits and a decision taken. Your Opinion that this change is not warranted will be noted in the final report.

Regarding the specific conditions referenced.

1. ASAWG does not agree that the golden rules could prevent certification of any future twin-engine aircraft in part because:
    - Total thrust loss failure condition due to most independent engine failures are not regulated by the golden rules, as these are active-active failure scenarios.

- Latent failure conditions that leave the airplane one engine failure away from a catastrophe mostly involve short at risk times (e.g. during takeoff, go-around, etc.). Consequently the resulting required relevant engine run reliability will be something less than 1E-4/hr.
- ICA's should be adequate to prevent most degradation to progress to the point of functional failure.
- The failure modes identified within combinatorial SSA's are typically limited to the known dominant failure modes of devices. This is because these are the failure modes that will dominate the risk of the top event. Only in single failure analysis would we look at the more obscure failure modes such as intermittent failures, specialized leaks, etc…

In any case, the airframe manufacturers in ASAWG have looked at their current airplanes and do not share this GE conclusion.

2. Your concern about failures which remain latent until some operating condition triggers an active failure is valid. It should be noted that there is a difference between degradation within specifications that do not make the engine "fail" to perform as intended and those which do. The former are not covered by the 25.1309(b)(4) rule, but would be precluded by the "no single failure" provisions of both 25.901(c) and 25.1309(b) (as they would set up a single cascading catastrophic failure). Hence these would need suitable design or maintenance provisions (ICA's) to prevent their occurrence. The later would need to be considered under 25.1309(b)(4), but as they would typically only be critical during some "at risk time". Hence, again the required "good" engine run reliability would be less than the 1E-5/hr criteria. The "out of spec" degradation of the "bad" engine itself would have to be detected and corrected in accordance with the 1E-3 criteria. However, in meeting that criterion, conditional probability credit could be taken for the percentage of "good" engine IFSD that would occur under operating condition that would trigger the "bad" engine failure. So, this is the one area of potential and intentional impact.

3. While the IFSD impact of a blade failure is relevant, it should be noted that any "engine rotor failure" related impacts (e.g. unbalanced loads, debris impact, etc.) are specifically excepted from these rules.

4. We do not understand the relevance of the hot air leak on the fire detector as that would be a single active failure resulting in at most a single engine safe shutdown.

6.4.1.6.6 TCCA

<u>TCCA submitted the following dissenting opinion:</u>

<u>OPINION #1:</u>

The proposed rule for 25.1309(b)(4)(ii) defines the limit latency criteria using the terminology "on the order of". This terminology is found currently in AC 25.1309-1A and the Arsenal revised AC 25.1309 as guidance for defining (from a numerical probability standpoint) the meaning of "extremely improbable", "extreme remote", etc. The use of this terminology does not have any precedent in current regulatory standards. TCCA believes that the use of this terminology in a rule of general applicability, without further definition or boundaries, could lead to inconsistent interpretation by authorities and applicants alike.

The current application of the terminology “on the order of” in 25.1309 compliance exercises has been as a means of recognizing uncertainty in statistical analyses. In this process there have been a wide range of opinions of the boundaries associated with this terminology, a fact that was confirmed through the course of the ASAWG meetings. As a result, TCCA believes that a definition accompanying the proposed rule for the meaning of “on the order” should be included in the ASAWG revised AC 25.1309 to provide less ambiguous guidance for the authority and the applicant.

ASAWG disposition to OPINION #1:

As stated earlier, the "on-the-order-of" in 25.1309 compliance exercises has been a means of recognizing uncertainty in statistical analysis and as the FAA has pointed out this is addressed on a case by case bases based on the maturity and depth of data being used to establish compliance to the quantitative number. SAE documents ARP4761 and ARP4754 address these uncertainties and highlight the need to validate the failure rates being used to show compliance. The ASAWG believes the current approach using "on-the-order-of" has shown to be adequate over the past 40 years and there is no need to change that now. This should apply to a rule or guidance.

The TCCA comment requests a definition be added associated with the term "on the order of". This may be problematic given that current AC meaning recognizes conservatism in the numerical analysis while for rule the term on the order is more dependent on the inspection intervals chosen. The applicant may want to reduce out of phase inspections, there may be practical limits based on how much the applicant can reduce the inspection interval based on access, frequency of maintenance induced errors. Typically for the first inspection period maintenance checks should be limited to those functional checks that can verified by pulling CB etc. rather than disassembly.

OPINION #2:

The ASAWG Task Four Report contains a proposal to modify the Arsenal revised AC 25.1309 version to include a new section 9. (b)(6) related to latent failures with guidance identifying the intent that they be eliminated wherever practical. TCCA agrees with this approach and believes it is an important protocol especially for those instances where means of avoiding latent failures has proven to be practical, or in the interests of maintaining best practices. As a result, TCCA recommends that this proposed new section of the ASAWG revised AC 25.1309 be amended to include a statement to this effect that will support the efforts of the ASAWG to provide a specific risk standard for latent failures that can replace existing ARAC proposals. To achieve this objective TCCA would recommend addition of the following statement to paragraph 9.(b)(6) of the ASAWG revised AC 25.1309:

“Where means of avoiding significant latent failures that can contribute to catastrophic failure conditions is considered or has been shown to be practical (e.g. thrust reverser systems), such means shall be applied. ”

The most notable case in this respect would be the ARAC proposed 25.933(a)(1) for thrust reversers where specific reference to an example of accepted current practices would strengthen the proposed 25.1309(b)(4) rule.

ASAWG disposition to OPINION #2:

Wishes to add to AC “Where means of avoiding significant latent failures that can contribute to catastrophic failure conditions is considered or has been shown to be practical (e.g. thrust reverser systems), such means shall be applied.” may invoke current T/R SR methodologies or quantitative criteria. There was a lot of discussion within the ASAWG on giving examples and the potential for misunderstanding or application, not to mention this was supposed to be a generalized requirement applicable across all systems. The statement "Whenever practical, these latent failures should be avoided. Means of avoidance include but are not limited to: eliminate the latent failure as discussed in paragraph 9(c) or add redundancy." was intended to do just what TCCA was after without being overly prescriptive.

A lot of discussion of individual design requirements such as those found in the Doors or Stall Warning was felt the way to handle this requirement and not in a general guidance documents such as the proposed AC/AMC 25.1309.

OPINION #3:

The criteria proposed by 25.1309(b)(4)(ii) for limiting the exposure to significant latent failures focuses on those that in combination with a single evident failure will lead to a catastrophic failure condition. TCCA has pointed out on previous occasions that the proposed revision to the Arsenal revised AC 25.1309 paragraph 11.g introducing the statement “single failures in combination with an operational or environmental condition that lead to a catastrophic failure condition may be allowed on a case-by-case basis”, may have inadvertently left a gap in the consideration of significant latent failures. For example, it is possible with the proposed rule change and AC revision that the presence of a cargo fire (i.e. an operational condition occurring independent from any aircraft system failure) in combination with a latent failure of the cargo fire detection or suppression system leading to a catastrophic failure condition would not be addressed by the criteria of 25.1309(b)(4)(ii).

The current Arsenal AC 25.1309 guidance material defines a significant latent failure as “… one which would in combination with one or more specific failures or events result in a Hazardous or Catastrophic Failure Condition.”

A latent failure of a cargo fire protection system element would by the above definition be considered significant and not only because it provides a direct contribution to the catastrophic failure condition of an uncontrolled fire. These elements are also significant as they are integral components of the system providing the only means of protection against the operational condition under consideration. A case in point can be made from a comparison of the following recent rulemaking efforts:

• The design for security requirements instituted by the introduction of 25.795 places a significant emphasis on maintaining the integrity of the cargo fire protection systems from damage by an event external to any aircraft system (i.e. cargo compartment explosion). The means of compliance in the accompanying advisory circular implies that redundant distribution systems may even be required to ensure integrity of the fire extinguishant distribution system. The applicant in this instance is required to demonstrate a higher level of system availability in the presence of the operational condition.

• The regulatory changes to 25.772 and 25.795 for the enhanced cockpit door security designs also assessed the need to ensure that remote cockpit door locking systems have a level of reliability commensurate with the security function intended to support the operational strategies for intruder mitigation. In this instance, the relevant guidance material stated flightdeck door systems must be shown to comply with 25.1309(b)(1) and (b)(2) with a suitable reliability level on the order of 10-5 failure per flight hour.

As a result, TCCA believes that the revised Arsenal AC 25.1309 should be modified to state that the exposure to any latent failure in combination with an operational or environmental condition that leads to a catastrophic failure condition should be limited accordingly by the criteria of 25.1309(b)(4)(ii). Alternatively, having those systems that contain such significant latent failures be required to achieve a reliability level commensurate with the approaches used in the above rulemaking examples (i.e. failure rates in the improbable range) may also be considered acceptable.

<u>ASAWG disposition to OPINION #3:</u>

Requesting reliability guidance for a single latent failure in combination with operational or environmental conditions is not limited to just latent conditions but all conditions. The fire detection and/or suppression system is just one example. It was felt by the Group that emphasis should be placed on properly categorizing the functional hazard then it was trying to force a reliability criterion on a system because of an inherent latency tendency. The variability in the probabilities of external and/or environmental conditions and the difficulty in validating these probabilities also make it hard to determine the correct reliability criterion. The concern would be that you drive the design to be detectable but give up reliability and thus true availability.

The discussion above to the TCCA OPINION #2 is also applicable. The example given by TCCA is the cargo fire detection and suppression systems because it is related to an external event that is not deterministic. This is unlike the engine fire detection and suppression system which is based on system design and the hazard that design may introduce. The method that should be employed for systems that their criticality is dependent on some external event (e.g. a stall barrier system, TAWS, etc.) should be covered by reliability guidance specific to that system and not by an aircraft level criteria that is only specific to latency.

6.4.1.6.7 Rockwell Collins

<u>Rockwell Collins submitted the following dissenting opinion:</u>

Rockwell Collins believes that modifications to the current regulations and associated certification process for avionics systems are unnecessary without a demonstrated industry "safety need" based on in-service accident or incident data. However should the industry produce this documented need, then Rockwell Collins believes that the Latent Task Recommendations are reasonable from a technical point of view.

ASAWG disposition of EASA Dissenting opinion:

As stated earlier, the key benefit Industry saw after several years of review and discussion was harmonization and consistency across all systems and between various regulation bodies. Early, in the Task 4 efforts TAEIG identified to the ASAWG that documented safety benefits would be difficult if not impossible and the focus should be placed on harmonization and consistency. The benefits identified by the working group of implementing the proposed changes would be invalidated without the complete implementation of all the changes in total by both the FAA and EASA. Therefore, it was a unanimous position from manufacturers that the proposed changes are either implemented in total or should not be implemented at all. Unlike previous working groups that were tasked to respond to a specific event or threat that had occurred, this effort is more of a harmonization across the aircraft and regulatory bodies. The identification of potential measurable safety benefits would require a forecast of a potentially hazardous or catastrophic event, therefore no safety benefits were identified.

6.4.2 Aging & Wear Task

In accordance with the ASAWG tasking, the ASAWG assessed the specific risk aspects of aging & wear and developed a recommendation that:

- Clarifies appendix 3, b (1) of AC 25.1309 (Arsenal) / AMC 25.1309 for the consideration of system component aging & wear aspects.

  Note: Although it is recognized that a revision of 25.1529, AC / AMC 25.19 and App. H 25.4 is out of the scope of the ASAWG ARAC tasking, the recommended changes provided in this section may require revision of 25.1529, AC / AMC 25.19 and App. H 25.4.

The following Aging & Wear Task 4 Recommendation gives its benefits, applicability, the recommendation itself with rationales and dissenting opinions.

6.4.2.1 Benefits of the Recommendations

The proposed change increases safety by providing applicants and regulators clear guidance that can be applied consistently across systems to

- Ensure consistent documentation of system component replacement times that are necessary to protect against aging and wear out.

6.4.2.2 Applicability of the Recommended Rules/ACs

These changes will apply to new TC or STC, if required according to change product rule, and will not be applied retroactively.

6.4.2.3 The Recommendations

Changes to SDAHWG recommended AC 25.1309 (Arsenal) / AMC 25.1309

Revise appendix 3, b (1), as follow:

From: *“The individual part, component, and assembly failure rates utilized in calculating the "Average Probability per Flight Hour" should be estimates of the mature constant failure rates after infant mortality and prior to wear-out and should be based on all causes of failure (operational, environmental, etc.). Where available, service history of same or similar components in the same or similar environment should be used”.*

To: *“The component failure rates utilized in calculating the "Average Probability per Flight Hour" should be estimates of the mature constant failure rates after infant* *mortality and prior to wear-out. For components whose probability of failure may be associated with non-constant failure rates within the operational life of the aircraft, reliability analysis may be used to determine component replacement times. In either case, the failure rate should be based on all causes of failure (operational, environmental, etc.). Where available, service history of same or similar components in the same or similar environment should be used.*

Aging and wear of similarly constructed and similarly loaded redundant components directly leading to or when in combination with one other failure leads to a catastrophic or hazardous failure condition should be assessed when determining scheduled maintenance tasks for such components.

Replacement times necessary to mitigate the risk due to aging and wear of those components whose failures could lead directly or in combination with one other failure to a catastrophic or hazardous failure conditions within the operational life of the aircraft should be assessed through the same methodology as other scheduled maintenance tasks required to satisfy 25.1309 (e.g. AC / AMC 25-19) and documented in the Airworthiness Limitation Section as appropriate".

Rationale: ASAWG recognized that the Draft AC 25.1309 (Arsenal) / AMC 25.1309 currently addresses aging and wear issue: *"… Average Probability per Flight Hour" should be estimates of the mature constant failure rates after infant mortality and prior to wear-out…"*

Appendix 3, b (1) of AC 25.1309 (Arsenal) / AMC 25.1309 was proposed to be modified to clarify the consideration of system component aging & wear aspects. It was recognized by the ASAWG that replacement times associated to system components whose probability of failure may be associated with non-constant failure rates within the operational life of the aircraft have not been treated in same manner across applicants and across systems from a single applicant.

The recommended change ensures consistent documentation of system component replacement times that are necessary to protect against aging and wear out. The following aspects are taken into account by the recommended change:

- By referencing to "*the operational life of the aircraft*" the recommended change avoids that replacement times being identified on all components that exhibit an increased failure rate beyond its operational life.

- By referencing to *"… same methodology as other scheduled maintenance tasks required to satisfy 25.1309 (e.g. AC / AMC 25-19) and documented in the Airworthiness Limitation Section…"* the recommended change mentions the appropriate place for documenting the replacement times.

- By referencing to *" ...those components whose failures could lead directly or in combination with one other to a catastrophic or hazardous failure conditions..."* the recommended change avoids that items (filters, batteries, etc…), which have to fail in combination with many others to cause a catastrophic or hazardous functional failure condition have to be documented in the Airworthiness Limitation Section.

6.4.2.4 General Comments on Costs and Benefits of the Recommendations

None identified beyond section 6.4.2.1.

6.4.2.5 Alternatives considered and why they weren't chosen

The alternative of not making any of the changes described in section 6.4.2.3 was considered at each step of the review and recommendation development process. In each case, the benefits described in section 6.4.2.1 outweighed maintaining existing guidance that was not always applied in a consistent manner.

The final Aging & Wear Task 4 change recommendation was established by taking into account the comments from all organizations as received during Task 4.

6.4.3 MMEL Task

The final evaluation of the current policies and practices implemented by OEMs and the various regulatory organizations concerning the development and approval of the MMEL over the past several decades has consistently demonstrated a high level of reliability and comprehensiveness in maintaining the necessary safety margins that both the engineering and operations communities have come to expect and require. Our past and current MMEL development considerations have primarily been based on consideration of the "next worst case failure" and the impact of that failure on crew workload and the integrity of the aircraft after that failure. This report finds that these procedures have provided excellent aircraft safety margins and, as such, we recommend that these procedures be continued as the primary path for future MMEL development and approval. This report also recommends establishing a standardized numerical analysis methodology for proposed MMEL items – when a numerical analysis for a given MMEL dispatch configuration is considered useful. This report further recommends revising the Arsenal and current versions of AC 25.1309 / AMC 25.1309 statements relative to the MMEL. Dispatches with multiple inoperative MMEL items are handled separately by the FOEB and considered to be outside the scope of this proposed guidance.

6.4.3.1 Benefits of the Recommendations

When used to support a proposed MMEL item's qualitative assessment, the recommended numerical analysis guidance would provide a standardized methodology that would maintain fleet average reliability objectives.

6.4.3.2 Applicability of the Recommended Rules/ACs

These changes will apply to new TC or STC, if required according to change product rule, and will not be applied retroactively, unless requested by the applicant.

Changes to the Arsenal version of AC 25.1309 / AMC 25.1309, paragraphs 12.b.(1) and paragraph 12.d., and the current AC 25.1309 -1A, paragraph 12.d are recommended. These changes are intended to make it clear that reliability analyses concerning MMEL dispatches need not be included in the numerical analyses submitted for certification to show compliance with FAR/CS 25.1309(b).

6.4.3.3 The Recommendations

(A) Recommendations to Industry and the Authorities (FAA Flight Standards, EASA, TCCA, etc.) for potential incorporation into MMEL Development Process:

This guidance is provided as a recommendation to industry and the authorities, and is recognized as not the only means to support the primary qualitative justification for a proposed MMEL item; therefore, this guidance is not mandatory. It should also be recognized that the FOEB Chairpersons have the authority to request additional analyses. This guidance is not intended to be applied retroactively to approved MMELs.

This guidance recognizes that under MMEL conditions, single failures leading to a potentially hazardous or catastrophic failure condition are normally not permitted at dispatch.

The results of numerical safety assessment of MMEL allowed dispatch with an inoperative item may be used to supplement the qualitative safety assessment review with the Authorities.

Numerical safety assessments are recommended when both of the following considerations are met:

1) Relief is proposed for items, functions and/or systems involved in Catastrophic or Hazardous failure conditions, and MMEL procedures do not mitigate the failure condition by operational procedures, limitations or a maintenance action prior to dispatch, and

2) When the operation with the inoperative item leaves the aircraft one failure away from a Hazardous failure condition, or one or two failures away from a Catastrophic failure conditions.

Items for which a numerical assessment is carried out to supplement the qualitative MMEL development process in accordance with the above mentioned considerations should be reported. Items for which the probabilities per flight hour of 1E-8 for Catastrophic failure conditions and 1E-6 for Hazardous failure conditions are not met in that dispatch configuration, should be reviewed with the Authorities. The following guidance applies to these proposed dispatches: This guidance includes equations to control how long these configurations are allowed to exist, such that the fleet average objectives will be achieved (see logic flowchart provided in Figure 6-1).

For Catastrophic Failure Conditions:

- A probability per flight hour of ≤ 1E-8 is the objective when dispatching with the inoperative item. When this objective is met, no calculation for a maximum allowable dispatch time is considered necessary.

- A limited number of items may be considered when the 1E-8/FH objective is not met. In these cases, the maximum allowable probability per flight hour when dispatching with the inoperative item should not exceed 1E-7/FH, and the maximum dispatch time should be less than that calculated using the following Equation (1).

- The 1E-8/FH objective and 1E-7/FH upper limit apply to each catastrophic top event involving the inoperative-at-dispatch MMEL item. If more than one top level event is involved, the maximum allowable dispatch time should be the smallest of those calculated for the affected top events.

- Equation (1):

$$Max\_Disp\_Time_{CAT}[FH] = \frac{1 \cdot 10^{-9}[probability\_per\_FH]}{PF \cdot FR}$$

Where:
$Max\_Disp\_Time_{CAT}$ [FH] = Max Dispatch Time [flight hours]
PF [1/FH] = Probability of Failure Condition [per flight hour] under dispatch condition
FR [1/FH] = Failure Rate of proposed MMEL item [per flight hour]

For Hazardous Failure Conditions:

- A probability per flight hour of ≤ 1E-6 is the objective when dispatching with the inoperative item. When this objective is met, no calculation for a maximum allowable dispatch time is considered necessary.

- A limited number of items may be considered when the 1E-6/FH objective is not met. In these cases, the maximum allowable probability per flight hour when dispatching with the inoperative item should not exceed 1E-5/FH, and the maximum dispatch time should be less than that calculated using the following Equation (2).

- The 1E-6/FH objective and 1E-5/FH upper limit apply to each Hazardous top event involving the inoperative-at-dispatch MMEL item. If more than one top level event is involved, the maximum allowable dispatch time should be the smallest of those calculated for the affected top events.

- Equation (2):

$$Max\_Disp\_Time_{HAZ}[FH] = \frac{1 \cdot 10^{-7}[probability\_per\_FH]}{PF \cdot FR}$$

Where:
$Max\_Disp\_Time_{HAZ}$ [FH] = Max Dispatch Time [flight hours]
PF [1/FH] = Probability of Failure Condition [per flight hour] under dispatch condition
FR [1/FH] = Failure Rate of proposed MMEL item [per flight hour]

Dispatch times will primarily be based on operational considerations. Allowed MMEL dispatch times may be considerably less than the maximum times calculated.

Note: The two equations given above for maximum dispatch times for MMEL items or functions involved in Catastrophic or Hazardous failure conditions provides dispatch times that are compatible with the fleet average top level reliability requirements of FAR/CS 25.1309(b). Equation(1) would yield a maximum operating time in the particular configuration to be ≤ 1% of the fleet operating time when the dispatch configuration has a failure rate of 1E-7/FH.

Maximum dispatch times as calculated using the above equations or other appropriate methods, should be maintained by the applicant's operations/MMEL group. That group will work with the Flight Operations Evaluation Boards (FOEB/OEBs) to decide on an acceptable MMEL entry.

Example Aircraft Level:

When a quantitative analysis is desired to support the qualitative assessment of an MMEL inoperative item dispatch, the following example may be helpful:

a) Use the fault trees for the Catastrophic failure conditions affected by the proposed MMEL item, where that failure condition cannot be mitigated by operational procedures, limitations or a maintenance action prior to dispatch.

b) Review the fault trees to determine whether operation with the inoperative MMEL item (item probability set to 1) leads to a probability per flight hour (at dispatch) of ≤ 1E-8/FH.

- If Yes (≤ 1E-8/FH): No numerical analysis needed for maximum allowable dispatch time

- If No (> 1E-8/FH): go to c)

c) Calculate the Maximum Dispatch Time using equation Equation(1):

Example numbers:

- Probability of Failure (PF) condition per flight hour under Dispatch condition – determined from fault tree with probability of MMEL item to 1:

  PF: 3E-8/FH

- Failure Rate (FR) of proposed MMEL item per flight hour

  FR: 1E-4/FH

- Maximum Dispatch Time ≤ (1E-9)/[(3E-8) x (1E-4)]

  Maximum Dispatch Time ≤ 333 flight hours

This may result in a 10 day, Category C relief listing in the MMEL.

(B) Changes to Arsenal version of AC 25.1309 / AMC 25.1309 and AC 25.1309-1A:

The following recommended wording changes to the Arsenal version of AC 25.1309 / AMC 25.1309 will allow better coordination and improved clarity between the AC's /

AMC´s recommended certification compliance requirements for FAR/CS 25.1309 and this report's recommendations concerning the MMEL development process. The last paragraph, paragraph 12.d, is also contained in the current AC 25.1309 -1A. The following changes shown in paragraph 12.d are also recommended for the current -1A AC. The advisory circular for FAR/CS 25.1309 should not imply that MMEL configurations be included in the reliability analyses required by that regulation for aircraft certification.

The proposed changes to AC 25.1309 (Arsenal) / AMC 25.1309 paragraph 12.b.(1) and 12.d. are:

b. Maintenance Action. Credit may be taken for correct accomplishment of reasonable maintenance tasks, for both qualitative and quantitative assessments. The maintenance tasks needed to show compliance with FAR/CS 25.1309(b) should be established. In doing this, the following maintenance scenarios can be used:

(1) For failures known to the flight crew see paragraph 12.d.

(2) Latent failures will be identified by a scheduled maintenance task. If this approach is taken, and the Failure Condition is Hazardous or Catastrophic, then a CCMR maintenance task should be established. Some Latent Failures can be assumed to be identified based upon return to service test on the LRU following its removal and repair (component Mean Time Between Failures (MTBF) should be the basis for the check interval time).

c. Candidate Certification Maintenance Requirements.

(1) By detecting the presence of, and thereby limiting the exposure time to significant latent failures that would, in combination with one or more other specific failures or events identified by safety analysis, result in a Hazardous or Catastrophic Failure Condition, periodic maintenance or flight crew checks may be used to help show compliance with FAR/CS 25.1309(b). Where such checks cannot be accepted as basic servicing or airmanship they become CCMRs. AC/AMJ 25.19 details the handling of CCMRs.

(2) Rational methods, which usually involve quantitative analysis, or relevant service experience should be used to determine check intervals. This analysis contains inherent uncertainties as discussed in paragraph 11.e.(3). Where periodic checks become CMRs these uncertainties justify the controlled escalation or exceptional short term extensions to individual CMRs allowed under AC/AMJ 25.19.

d. Flight with Equipment or Functions Known to be Inoperative. An applicant may elect to develop a list of equipment and functions which need not be operative for flight, based on stated compensating precautions that should be taken, e.g., operational or time limitations, flight crew procedures, or ground crew checks. The documents used to show compliance with FAR/CS 25.1309, together with any other relevant information, should be considered in the development of this list. Experienced engineering and operational judgment should be applied during the development of this list. When more than one flight is made with equipment known to be inoperative and that equipment affects the probabilities associated with Hazardous and/or Catastrophic failure conditions, time limits may be needed for the number of flights or allowed operation time in that aircraft configuration. These time limits should be established in accordance with the recommendations contained in FAA Flight Standards Policy.

6.4.3.4 General Comments on Costs and Benefits of the Recommendations

MMEL - Provides a better foundation for potential harmonization between the FOEB and JOEB.

6.4.3.5 Alternatives considered and why they weren't chosen

None

6.4.3.6 Dissenting Opinions

None

Note: A number of discussions have been tracked in the attached appendix as a record of associated rational.

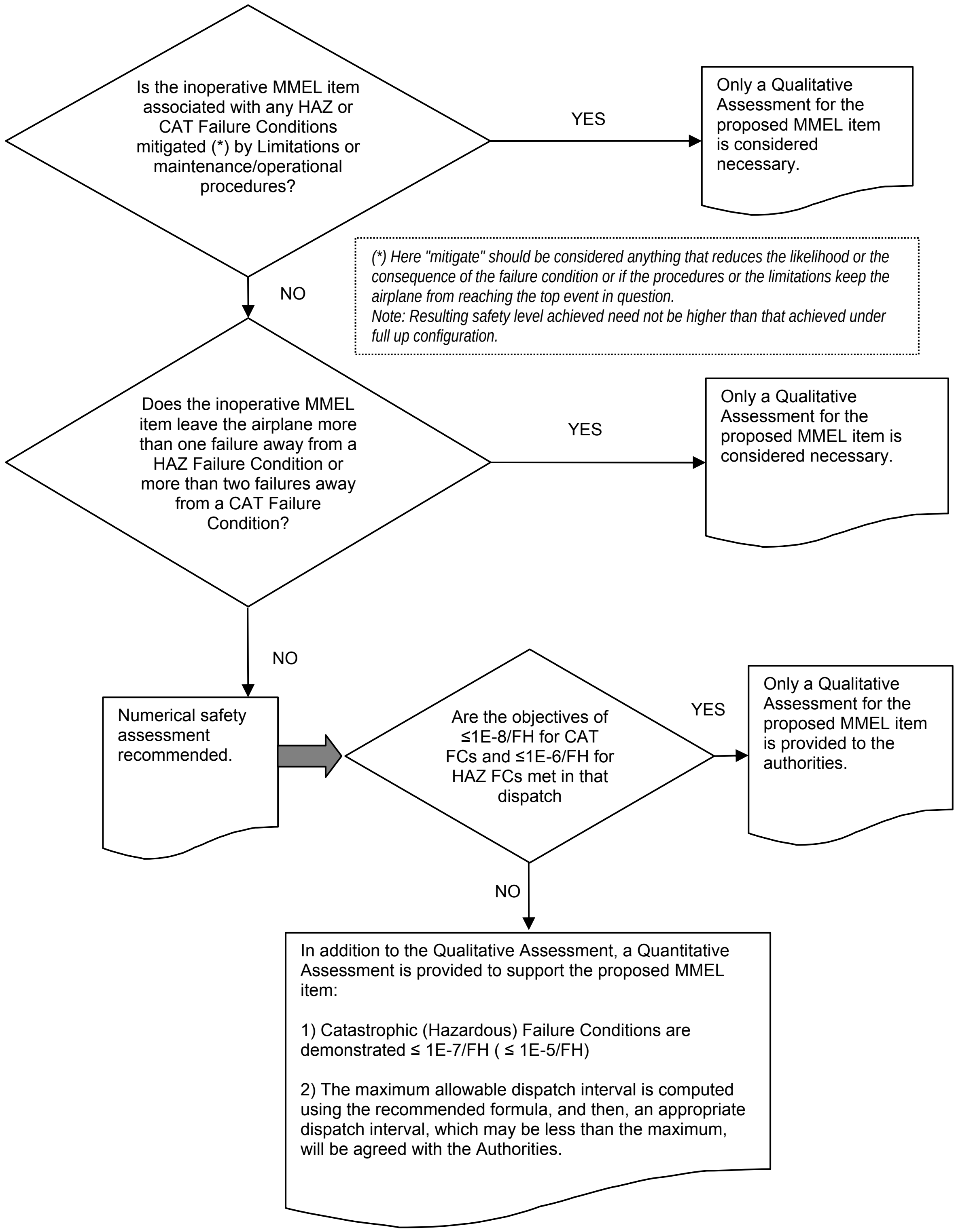


Figure 6-1 *Logic Flowchart to Support Numerical Analyses for Proposed MMEL Items*

6.4.4 Flight & Diversion Time Task

In accordance with the ASAWG tasking, the ASAWG assessed the specific risk aspects of Flight Phase, Maximum flight time versus average flight time, and Average diversion time versus maximum allowed diversion time and developed recommendations that:

- Clarify section 10 of AC 25.1309 (Arsenal) / AMC 25.1309 for the consideration of intensifying and alleviating factors particularly with respect to flight duration, flight phase, and diversion time.

- Clarify section 11 of AC 25.1309 (Arsenal) / AMC 25.1309 for how environmental or operational factors are combined with single failures to address inconsistency that has caused misunderstandings between the regulators and applicants.

- Revise Appendix 4 tables of AC 25.1309 (Arsenal) / AMC 25.1309 to clearly focus on environmental conditions and operational factors.

- Revise ETOPS AC 1535-1X Chapter 3 Paragraph 16.a (3) and (4) for the use of mission time and diversion times in ETOPS safety analysis.

The following Flight & Diversion Time Task 4 Recommendation gives its benefits, applicability, the recommendation itself with rationales and dissenting opinions.

6.4.4.1 Benefits of the Recommendations

The proposed changes increase safety through elimination of errors in the application of the guidance and by providing applicants and regulators clear guidance that can be applied consistently across systems.

- Treat flight time, flight phase and diversion time in the FHA in same manner across applicants and across systems from a single applicant.

- Ensure correct hazard classification in FHAs take into account intensifying factors, such that specific risk concerns worthy of being addressed are not overlooked.

- Eliminate confusion with respect to the compounding nature of factors in defining the hazard classifications in an FHA.

- Eliminate the misunderstandings due to unclear guidance on how environmental or operational factors are combined with single failures.

- Appendix 4 tables of AC 25.1309 (Arsenal) / AMC 25.1309 modified to eliminate confusion between failures and environmental conditions and operational factors.

- Harmonized use of average long-range flight duration and maximum diversion time for both type 1 and type 2 systems in compliance to the new ETOPS rule (25.1535).

6.4.4.2 Applicability of the Recommended Rules/ACs

These changes will apply to new TC or STC, if required according to change product rule, and will not be applied retroactively.

6.4.4.3 The Recommendations

6.4.4.3.1 A. Changes to SDAHWG recommended AC 25.1309-Arsenal / AMC 25.1309. Changes are shown in **bolded** letters.

- Add specific risk and specific risk of concern definitions to Section 5 Definitions: "Specific Risk. The risk on a given flight due to a particular condition".

  Rationale: New terms used to define and scope specific risk.

- Revise paragraph 10c(2)(ii) to:

  (ii) Regardless of the types of assessment used, the classification of Failure Conditions should always be accomplished with consideration of all relevant factors; e.g., system, crew, performance, operational, external. ~~*Examples of factors include the nature of the failure modes, any effects or limitations on performance, and any required or likely crew action.*~~ *It is particularly important to consider factors that would alleviate or intensify the severity of a Failure Condition. Where flight duration, flight phase, or diversion time can adversely affect the FHA outcome, they must be considered as intensifying factors. Other intensifying factors include conditions (not related to the failure, such as weather or adverse operational or environmental conditions), which reduce the ability of the crew to cope with a Failure Condition. An example of an alleviating factor is the continued performance of identical or operationally similar functions by other systems not affected by the Failure Condition. Combinations of factors need only be considered if they are anticipated to occur together.*

  Rationale: This paragraph was modified to clarify the consideration of intensifying and alleviating factors particularly with respect to flight duration, flight phase, and diversion time. It was recognized by the ASAWG that flight time, flight phase and diversion time have not been treated in the FHA in same manner across applicants and often across systems from a single applicant. While this is not strictly a specific risk concept, it is an imperative that the FHA define the hazard classification for a given failure condition correctly, and without properly accounting for intensifying factors in the FHA, specific risk concerns, worthy of being addressed, may be missed while still in this criteria setting activity.

  Specific changes include deleting the second sentence in the paragraph based on the rationale that this sentence does not provide any useful guidance and adds confusion by mixing up relevant factors with effects of failure. A new sentence was added to specifically address flight duration, flight phase and diversion time as relevant factors, and the following sentence was modified slightly to accommodate this sentence and not lose the existing examples of intensifying factors.

The final sentence of the paragraph was added to address confusion with respect to the compounding nature of factors in defining the hazard classifications in an FHA. Obviously, compounding factors that are in and of themselves extremely improbable need not be considered, but the question of what must be considered is a constant source of confusion both with the regulatory specialists and the applicants. The sentence provided seemed to best capture both historical concepts and the concern that the FHA is a qualitative assessment, and therefore to avoid terms that would be interpreted as requiring a probabilistic assessment. Hence the words "Combinations of Factors need only be considered if they are anticipated to occur together". While it was unavoidable that this still has a certain probabilistic aspect to it (i.e. FAA has already equated "not extremely remote" with "anticipated to occur" via latent failure specific risk provisions such as those used for compliance with FAR25.901(c), FAR25.981(a)(3), etc.) It is the intent of this discussion to make clear that a probabilistic assessment of what to consider as relevant factors is not required, but a qualitative consideration regarding the likelihood of factors and their independence should be part of the assumptions documented with functional failure described in the FHA.

- Revise section 11g to:

Operational or Environmental Conditions. A probability of one should usually be used for encountering a discrete condition for which the airplane is designed, such as instrument meteorological conditions or Category III weather operations. However, Appendix 4 contains allowable probabilities which may be assigned to various operational and environmental conditions for use in computing the average probability per flight hour of failure conditions, ~~resulting from multiple independent failures,~~ without further justification. Single failures in combination with operational or environmental conditions leading to catastrophic failure conditions are in general not acceptable. Limited cases that are properly justified, ~~(e.g. operational events or environmental conditions that are extremely remote)~~ may be considered on a case-by-case basis (e.g. operational events or environmental conditions that are extremely remote).~~ (cases that had been accepted in the past are e.g. operational events or environmental conditions that are extremely remote RTO for a cause independent from the failure).~~

Appendix 4 is provided for guidance and is not intended to be exhaustive or prescriptive. At this time, a number of items have no accepted standard statistical data from which to derive a probability figure. However, these items are included for either future consideration or as items for which the applicant may propose a probability figure supported by statistically valid data or supporting service experience. The applicant may propose additional conditions or different probabilities from those in Appendix 4 provided they are based on statistically valid data or supporting service experience. The applicant should obtain early concurrence of the Certification Authority when such conditions are to be included in an analysis. When combining the probability of such a random condition with that of a system failure(s), care should be taken to ensure that the condition and the system failure(s) are independent of one another, or that any dependencies are properly accounted for.

Rationale: During the ASAWG's investigation of how single failures are treated for specific risk purposes, the team found that paragraph 11g has unclear guidance for how environmental or operational factors are combined with single failures. The first paragraph above was modified to address this inconsistency within the paragraph that has caused misunderstandings between the regulators and applicants. The contradictory text is in the second sentence where is stated "However, Appendix 4 contains allowable probabilities which may be assigned to various operational and environmental conditions for use in computing the average probability per flight hour of failure conditions resulting from multiple independent failures, without further justification."; and the last sentence in the third paragraph above which states "When combining the probability of such a random condition with that of a system failure, care should be taken to ensure that the condition and the system failures are independent of one another, or that any dependencies are properly accounted for." The second sentence of the first paragraph has been modified a new third and forth sentence added to more clearly state when multiple and single failures can combine with the allowable probabilities of Appendix 4. While these inputs are to an average risk calculation method, how operational and environmental conditions are handled whether in average or specific risk calculations is related to the section 10 material above.

- Revised Appendix 4 lead paragraph, Environmental Factors and Other Events table:

APPENDIX 4. ALLOWABLE PROBABILITIES.

The following probabilities may be used for environmental conditions and operational factors not due to airplane failure causes in quantitative safety analyses:

Environmental Factors

Condition	Model or other Justification	Probability
Dispatch into Appendix C Icing		1
Icing outside Appendix C		No Accepted Standard data
Probability of specific icing conditions (largest water droplet, temperature etc) within a given flight		No accepted standard data
Head wind >25 kts	AC 120-28	10-2 per flight

Condition	Model or other Justification	Probability
during takeoff and landing	JAR-AWO	
Tail wind >10 kts during takeoff and landing	AC 120-28 JAR-AWO	10-2 per flight
Cross wind >20 kts during takeoff and landing	AC 120-28 JAR-AWO	10-2 per flight
Limit design gust and turbulence	FAR/JAR 25.341(Under review by Structures Harmonization Working Group)	10-5 per flight hour
Air temperature < -70oC		No accepted standard data
~~Lightning strike~~		~~No accepted standard data~~
~~HIRF conditions~~		~~No accepted standard data~~

Other Events

Event	Model or other Justification	Probability
Fire in a lavatory **not due to airplane failure causes**		No accepted standard data
Fire in a cargo **compartment not due to airplane failure causes**		No accepted standard data
~~Fire in APU compartment~~		~~No accepted standard data~~
~~Engine fire~~		~~No accepted standard data~~
~~Cabin high altitude requiring passenger oxygen~~		~~No accepted standard data~~

Rationale: During the ASAWG's investigation of single failures as described in 11g rationale above, the team found that Appendix 4 required to be clearly focused on environmental conditions and operational factors. Some of the items listed as "Other Events" in the table in Appendix 4 are system failures, not environmental or operational conditions. These failures were removed from the table and remaining items revised to delineate from system failures. No attempt was made by the team to modify the table for completeness or re-justify the probability values.

Reference to HIRF and Lightning were removed from the table to avoid confusion that numerical analyses are always required for compliance to 25.1309 when effects of HIRF and lightning are considered. ~~coordinate with existing rules changes that control HIRF and Lightning by qualitative means. FAR25.1316 and 25.1317 and their respective ACs (AC 20-158 for HIRF and AC 20-136A for lightning) and guidance material ARP5583 (Guide to Certification of Aircraft in a High Intensity Radiated Field (HIRF) Environment) and ARP5415A (User's Manual for Certification of Aircraft Electrical/Electronic Systems for the indirect Effects of Lightning) document the qualitative means."~~

6.4.4.3.2 B. ETOPS (changes to draft AC 1535-1X)

- The actual recommendation revising draft AC 1535-1X Chapter 3 Paragraph 16.a (3) and (4):

(3) Airplane system safety assessments for ETOPS are addressed under the specific objectives of FAR25.901(c) and 25.1309, considering the maximum flight time and longest diversion time for which the applicant seeks approval. ~~*The ETOPS rule does not modify how ETOPS airplane safety assessments were conducted using the guidelines in AC 120-42A.*~~ *The main impact that ETOPS will have on airplane system safety assessments is a potentially more severe hazard when considering the long-range and maximum ETOPS diversion distances associated with a maximum ETOPS flight. For example, a failure(s) in an airplane's environmental control system resulting in either a very hot or very cold cabin temperature could be potentially life-threatening during a five-hour diversion, whereas the same failure would merely be an uncomfortable inconvenience during a 30-minute diversion. What may be considered a minor or major effect during a short diversion may have a hazardous or even catastrophic effect over a longer period. Such time-related effects must be considered in the safety assessments of these types of failures to ensure that any potentially unsafe failure conditions are identified and the proper hazard classification defined. Section K25.1.1 of Appendix K requires the applicant to show that the airplane systems meet the safety objectives of FAR25.901(c) and 25.1309 for any failure condition that has an more severe failure effect when considering a maximum ETOPS diversion following the failure.*

(4) Considering the maximum flight time per FAR K25.1.1 does not mean that the numerical probability objectives (for example, on the order of 1E-9/hr for a catastrophic failure condition, on the order of 1E-7/hr for a hazardous failure condition, etc.) for showing compliance with FAR25.1309(b) must be met solely

by using the maximum flight time. For ETOPS group 1 ~~significant systems, an applicant may use the "maximum ETOPS mission time" instead. For ETOPS~~ ***and*** *group 2 significant systems, the probability calculations may be based on average fleet mission time for ETOPS operated aircraft, assuming a maximum diversion time. (Note - not average risk mission time for the whole fleet). The average fleet risk mission time for ETOPS operated aircraft should be estimated based on the applicant's expectations for how the ETOPS operated aircraft will be used in service. The average fleet risk mission time for ETOPS operated aircraft should include potential ETOPS routes within the maximum range capability of the airplane. This normally results in a longer average flight time than would be used for basic Part 25 certification of non-ETOPS airplanes. For ETOPS group 1* ***and group 2*** *~~significant~~ systems, where a diversion is the probable outcome of a failure condition, e.g. an engine shutdown, a maximum length ETOPS diversion should be assumed in the safety assessment. For example, as discussed in Paragraph (3) above, the cabin thermal environment should consider the maximum diversion time to define the hazard and compliance criteria. ~~For ETOPS group 2 significant systems, the average ETOPS flight time used in numerical probability analyses may be inclusive of all diversion times up to the maximum. The exception for group 2 ETOPS significant systems would be for failure conditions that are diversion time dependent. In those cases, the maximum ETOPS diversion time should be used.~~*

Rationale: Revise group 1 calculation approach from using maximum ETOPS mission time to using the average ETOPS flight duration. Harmonize advisory material to FAA and EASA expectations and pending guidance material.

The use of average fleet risk mission time for ETOPS operated aircraft is proposed to be consistent with the fleet average approach of 25.1309, considering the ETOPS fleet, and IL-20/GAI20X06 Appendix 2 and past EASA practice. This change does not affect system capability, capacity and performance, which should be sized for maximum mission time and maximum diversion time as appropriate.

6.4.4.4 General Comments on Costs and Benefits of the Recommendations

None identified beyond section 6.4.4.1.

6.4.4.5 Alternatives considered and why they weren't chosen

The alternative of not making any of the changes described in section 6.4.4.3 was considered at each step of the review and recommendation development process. In each case, the benefits described in the rationale section for each proposed change outweighed maintaining existing guidance that was not always applied in a consistent manner.

- HIRF and Lightning considerations in 25.1309, 25.1316, and 25.1317

The ASAWG deliberated exception of HIRF and lightning from 25.1309, but consensus was not achieved due to dissension from all of the certification authorities (ANAC, EASA, FAA, and TCCA.) However, the ASAWG agreed that HIRF and Lightning issues (identified below) should be addressed by a future committee with representation from Systems, Safety, and EME disciplines. The ASAWG concluded this discussion was both outside of the tasking and that the ASAWG did not have adequate representation from the EME community to collectively disposition the subjects listed below. With the exception of removing HIRF and Lightning from the Appendix 4 table for reasons noted above, status quo for H/L considerations should be maintained until that proposed future committee addresses them.

1. Because the failures of HIRF and Lightning protection features are often latent, clear guidance should be provided as to whether qualitative evaluation of failure conditions involving protection features is adequate, and if so, how should such qualitative evaluation be performed. Establish a basis for a qualitative assessment of the architecture to confirm that it is robust and it can withstand such risk.
2. Current practice typically does not include the probabilities of these environmental conditions in safety analyses for initial certification, although the probabilities at times are included in the safety analyses for continued airworthiness determination. If numerical analysis is needed to show compliance, guidance on how this is done should be provided.
3. Instructions for continued airworthiness and its use for HIRF and Lightning Protection features should be clearly explained, particularly if credit is allowed in qualitative and quantitative analyses.
4. AC 20-158 for HIRF and AC 20-136A for lightning, and guidance material ARP5583 (Guide to Certification of Aircraft in a High Intensity Radiated Field (HIRF) Environment) and ARP5415A (User's Manual for Certification of Aircraft Electrical/Electronic Systems for the indirect Effects of Lightning) should be re-evaluated along with AC 25.1309 to establish unambiguous guidelines towards means of compliance to these rules for HIRF and Lightning.
5. Provide explicit guidance for Failure modes and Effects Analyses and Particular Risk Assessments on how to manage HIRF and Lighting protection features if there are any unique requirements.
6. Clear guidance on relationship to HIRF and Lightning Test Levels with respect to common cause aspect of the threat.
7. Ensure that guidance establishes the correct system architecture requirements to protect the airplane when the airplane configuration changes due to various reasons (MMEL, latent failures, corrosion, etc.), as opposed to setting only test levels.
8. There is a need for Lightning assessment under 25.1309 for mechanical systems, in light of ARP 5577 which addresses mechanical systems in a general sense.

6.4.4.6 Dissenting Opinions

6.4.4.6.1 Garmin dissenting opinion on changes to AC 25.1309 / AMC 25.1309 paragraph 11g:

To be consistent with the agreed approach to not address HIRF and Lightning in the ASAWG, but rather to maintain the status quo until a new ARAC team can fully address the issues defined, Garmin recommends that the last two sentences of 1st paragraph of 11g be revised from: "Single failures in combination with operational or environmental conditions leading to catastrophic failure conditions are in general not acceptable. Limited cases that are properly justified, (e.g. operational events or environmental conditions that are extremely remote) may be considered on a case-by-case basis (e.g. RTO for a cause independent from the failure)."

To: "Single failures in combination with operational or environmental conditions leading to catastrophic failure conditions are in general not acceptable. Limited cases that are properly justified may be considered on a case-by-case basis."

The new text may be open enough to leave existing certification practice for HIRF and lightning unchanged until this issue can be resolved. In a separate issue the current AC task 4 report 11g proposal does not provide any other criterion for determining acceptability other than "single failure in combination with operational events or environmental conditions that are extremely remote". As such in practice it may become the only acceptable criterion even though this may not be appropriate for all situations (e.g. HIRF/L) and is not the intent of the ASAWG. I have been concerned that there is the potential that existing AC numerical reliability and design assurance objectives could be superseded by the new 25.1309 AC/AMC guidance. Specifically when considering operational conditions such as CFIT and entry into stall that are not extremely remote (< 1E-7/FH).

The example criterion is more conservative than other existing AC/AMC system guidance. For example TAWS and stick pusher availability is 1E-4 and level C. No single failure implies multiple redundancy and level A software for loss of function. By removing the example criteria this concern is diminished and may allow me to recommend that the current Garmin recommendation to change the current criteria (see Garmin dissent) to the one below, be withdrawn.

<u>DISSENT EXAMPLE</u>: If the crew were to perform an abort and there was a throttle jam (after power set), the asymmetric thrust (on wing mounted engines) - because of one stuck throttle - will cause the aircraft to laterally depart the runway. For the purpose of the example this is assumed to be a potential catastrophic failure condition. The probability of a throttle jam was/is on-the-order-of 1E-7/FH. The exposure period for the jam - after power set and before V1 - is approximately 20 seconds. The probability of a jam is 1E-7(20/3600) = 5.5E-10. The probability of an abort due to an external event is about 1 in 2000 takeoffs. This is not extremely remote per the new AC guidance. The applicant cannot combine the "jam probability" with the "probability of an abort". Therefore the applicant does not meet the new "no single failure" criterion proposed by the ASAWG AC/AMC 25.1309 guidance.*

ASAWG disposition of Garmin Dissenting opinion - ASAWG reviewed Garmin's dissenting opinion above and recommended change to the wording of 11g. The ASAWG has agreed to remove the parenthetical "e.g. RTO for a cause independent from the failure" and the revised 11g is shown in 6.4.4.3.1 above. However, the ASAWG disagrees with the removal of the parenthetical "e.g. operational events or environmental conditions that are extremely remote". It was felt that the example "operational or environmental conditions that are extremely remote", offered an example for cases where one or more operational or environmental condition could be stacked up to represent an unrealistic failure condition. This is not intended to prevent other arguments such as the obscurity of the failure mode, but to provide one example of an acceptable criterion.

6.4.4.6.2 Garmin dissenting opinions on HIRF and Lightning considerations in 25.1309, 25.1316, and 25.1307:

Garmin provided dissenting opinions on the HIRF and Lightning considerations in 25.1309, 25.1316, and 25.1307 (see chapter 6.4.4.5 "Alternatives considered and why they weren't chosen").

Garmin Dissenting opinion (1):
Section 6.4.4.5 bullet 2:
Dissent: "The term safety analysis is too broad when related to probability of one assumption. Typically for EME a probability of 1 is limited to common cause analyses. Bullet 2 should also be clarified that numerical analysis is in relation to probabilistic criteria."
Recommendation: Current practice typically does not include the probabilities of these environmental conditions in common cause analyses for initial certification, although the probabilities at times are included in the safety analyses for continued airworthiness determination. If numerical analysis is needed to show compliance to probabilistic criteria, guidance on how this is done should be provided.

ASAWG disposition of Garmin Dissenting opinion (1):
ASAWG did not intend to imply that a probability of 1 should be used for analysis other than common cause analyses. The ASAWG does not believe this is conveyed by the sentence in bullet 2.

Garmin Dissenting opinion (2):
Section 6.4.4.5 bullet 5:
Dissent: It is not clear what this is asking for in relation to unique requirements. How can the new group provide FMEA & PRA guidance for undefined requirements? What is meant by the word "manage"? Testing ensures that there is no failure that can affect the full up airplane so what is the purpose of FMEA?

ASAWG disposition of Garmin Dissenting opinion (2):
Though it could perhaps be worded better, the intent of this bullet was to ensure that if the future committee identifies any unique requirements on how to treat HIRF and Lightning in FMEAs and PRAs, then the future committee should also provide guidance that is explicit for FMEAs and PRAs. Therefore no change is recommended to proposal at this time.

Garmin Dissenting opinion (3):
Section 6.4.4.5 bullet 5:
Dissent: This is already done today by the guidance provided in the HIRF/Lightning AC.
Recommendation: This bullet should be removed or otherwise clarify more specifically the concern.

ASAWG disposition of Garmin Dissenting opinion (3):
It was not clear to the ASAWG when reviewing the AC guidance that the test levels adequately addressed multiple units providing redundancy for a specific function. This was the intent of bullet 6. If the future committee concurs with the dissenting opinion that the existing guidance adequately addresses this issue, then recommendation can be ignored.

Garmin Dissenting opinion (4):
Section 6.4.4.5 bullet 7:
Dissent: The text of bullet 7 implies the current practice is unacceptable. The language should be more neutral. It is the new committee responsibility to determine what is acceptable.
Recommendation: The review should consider whether the current guidance/practice establishes adequate system architecture requirements to protect the airplane when the airplane configuration changes due to various reasons (MMEL, latent failures, corrosion, etc.).

ASAWG disposition of Garmin Dissenting opinion (4):
ASAWG disagrees that the Bullet 7 implies that the current practice is unacceptable. The intent was to identify the various aspects that the future committee should consider.

Garmin Dissenting opinion (5):
Section 6.4.4.6.1 Dissenting opinion
Dissent: The ASAWG disposition of the Garmin dissent does not address the first paragraph of the existing dissent (reference section 6.4.4.6.1, page 88). Further, Garmin wishes to modify its existing dissent to include the following paragraph. This paragraph will expand and clarify an existing point being made by Garmin, by the current text, which was not fully understood.
Recommendation: "The example [i.e. operational events or environmental conditions that are extremely remote] in paragraph 11g generated discussions with the ASAWG on its potential impact for HIRF/Lightning design and testing. It was recommended by the ASAWG that there should be a subsequent committee to address these issues raised as documented in section 6.4.4.5 of the report. However given that the AC 25.1309 may be released prior to the formation of committee or even regulatory acceptance of the recommendation it seems premature to adopt this example in the AC that could result in additional costs to applicant if interpreted to apply to HIRF and Lightning. These cost aspects have yet to be determined by the ASAWG. For example, the interpretation of this criterion could result in the demonstration by test of multiple level A paths to mitigate HIRF and lightning effects. "

ASAWG disposition of Garmin Dissenting opinion (5):

Report is clearly states that "With the exception of removing HIRF and Lightning from the Appendix 4 table for reasons noted above, status quo for H/L considerations should be maintained until that proposed future committee addresses them."

Appendix A

6.4.5 Appendix to Latent Failure Task

6.4.5.1 Large Aircraft Cost Worksheets

C:\Safety\TAEIG WG
Final Report\Latent\A

C:\Safety\TAEIG WG
Final Report\Latent\A

C:\Safety\TAEIG WG
Final Report\Latent\A

6.4.5.2 Large Business Aircraft Cost Worksheets

C:\Safety\TAEIG WG
Final Report\Latent\A

C:\Safety\TAEIG WG
Final Report\Latent\A

6.4.5.3 Cessna Cost Worksheets

C:\Safety\TAEIG WG
Final Report\Latent\A

6.4.5.4 Example of FAR/CS 25.1309(b)(4)

The following example illustrate how the quantitative criteria of FAR/CS 25.1309 (b)(4) is to be implemented. The methodology used is based on the identification of the minimal cut sets associated with the top event of the generic system level fault tree provided in Figure 7-1.

The term minimal cut set refers to the smallest set of components whose failure is sufficient to cause system failure or in this case the failure condition of concern. The list of cut sets should be produced by cut set order. This will group all dual order cut sets or failure combinations. The list of dual order cut sets should then be reduced further based on the probability of each cut sets. Dual failures whose probability is less than 1E-12/FH need not be considered for further analysis. The entire list of cut sets of the fault tree in Figure 7-1 are provided in Table 7-1.

The cut sets that contain a basic event that is latent for more than one flight are then identified from the list in Table 7-1. The probability of each of these latent events should be less than 1E-3. Then group those dual order cut sets that contain the same latent basic event. For each group assume that latent basic event has failed and sum the remaining active failure probabilities. For each group the sum of the active failures should be less than 1E-5/FH. An alternative but more conservative method would be to rerun the fault tree probability calculation assuming for each model rerun that a different latent basic event had failed.

The result of the limit latency analysis is provided in Table 7-1. Events L002, L003, L004 and L005 comply with the requirements of FAR/CS 25.1309(b)(4)(ii), Latent event L001 is not in compliance.

The result of the residual risk analysis is also provided in Table 7-1. Cutsets #1, #2 and #5 comply with the requirements of FAR/CS 25.1309(b)(4)(i), Cutset #3 fails to comply due to active event A002.

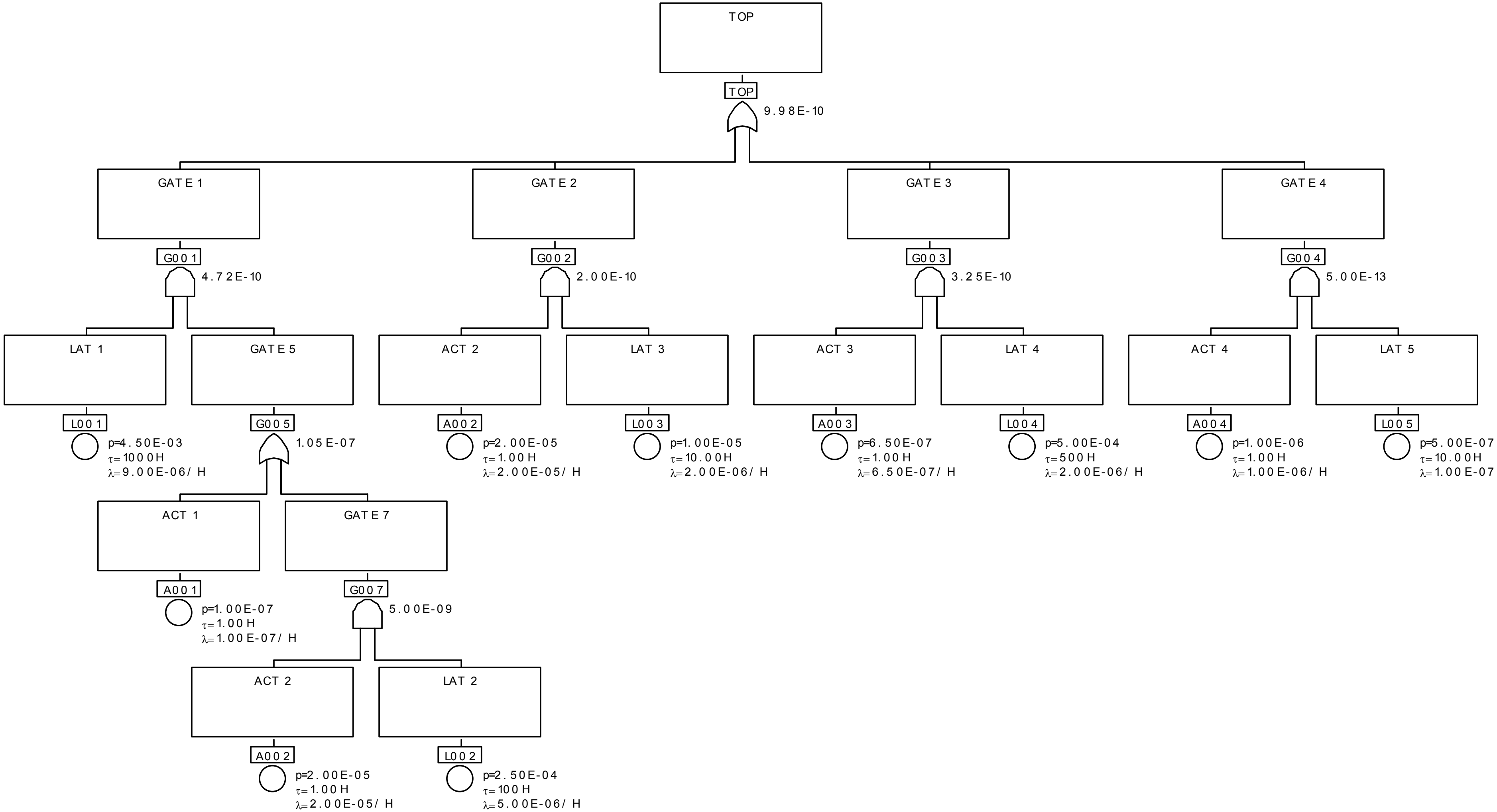


Figure 7-1: Example of FAR/CS 25.1309(b)(4) Fault Tree

TOP Event = 9.98E-10/FH							
#	Inputs	Description	Rate (per hour)	Exposure (hour)	Event Prob	Probability	Application of 25.1309(b)(4)
1	A001	ACT 1	1.0E-7	1	1.0E-7	4.50E-10	It does NOT meet the limit latency criterion since L001 is higher than 1E-3.
	L001	LAT 1	9.0E-6	1000	**4.5E-3**		
2	A003	ACT 3	6.5E-7	1	6.5E-7	3.25E-10	It does meet both residual risk and limit latency criteria.
	L004	LAT 4	2.0E-6	500	5.0E-4		
3	A002	ACT 2	2.0E-5	1	**2.0E-5**	2.00E-10	It does NOT meet the residual risk criterion since A002 is higher than 1E-5/FH.
	L003	LAT 3	2.0E-6	10	1.0E-5		
4	A002	ACT 2	2.0E-5	1	2.0E-5	2.25E-11	Although L001 is higher than 1E-3 and A002 is higher than 1E-5/FH, this is NOT applied since is more than dual failure combination. *Note: L001 is the same failure that contributes in failure combination #1.*
	L001	LAT 1	9.0E-6	1000	**4.5E-3**		
	L002	LAT 2	5.0E-6	100	2.5E-4		
5	A004	ACT 4	1.0E-6	1	**1.0E-6**	**5.00E-13**	Although It does meet both residual risk and limit latency criteria, this is NOT applied to this failure combination since it is lower than 1E-12/FH.
	L005	LAT 5	1.0E-7	10	**5.0E-7**		

Flight Time = considering 1 hour of flight.

$$P\quad[Lat\ x] = \frac{FR \times T}{2}$$

Table 7-1: Example of FAR/CS 25.1309(b)(4) Minimal Cut Set

6.4.5.5 Comments to chapter 6.4.1

The following comments to chapter 6.4.1 were provided. These general comments should be reviewed when preparing the final NRPM.

Comments from ANAC:

Comments from
ANAC to Final ASAW(

Comments from the FAA:

Comments from FAA
to Final ASAWG Repo

Note: The dissenting opinion #1 and #2 and the significant comment #1 and #2 in the above attached file are reviewed in detail in chapter 6.4.1.6 “Dissenting Opinion and Discussion” of this report.

Comments from the Boeing:

Boeing agrees with the recommendation of the ASAWG, however, we request that it be noted in the report that our acceptance is contingent on the entire set of recommendations being followed. Selecting particular items out of the recommendation (like implementing the latent rule and guidance changes in 25.1309 without changing the associated specific risk regulations (25.671, 25.933, etc.)) will cause Boeing to re-evaluate the costs and benefits of this change.

Boeing also requests that it be documented that applicability is clear, the rule and guidance are not applied retroactively; i.e. Change Product Rule 14 CFR 21.101 applies.

Finally, Boeing wants to ensure that it is clear that the failure condition considered in the new latency rule is not the result of a single failure and an environmental or operational condition (covered by paragraph 11g of AC 25.1309 proposal) and recommends additional discussion of this in the preamble to the rule.

Comments from Garmin:

Comment (1):
Section 6.4.1, 3rd paragraph:
Comment: This sentence is incomplete. What happens if these changes are not implemented is not conveyed by the sentence.

Recommendation: This sentence should convey that without these changes the benefits of section 6.1.4.1 are not met.

Comment (2):

Section 6.4.1 8th paragraph:
Comment: The introductory words to this sentence can be stated more clearly.

Recommendation: Change “The limitations to include this criteria…” to “The decision to limit this criteria…”

Comment (3):

Section 6.4.1 9th paragraph:
Comment: The phrase statistical fall out does not seem to be accurate. The applicable AC text refers to adequate design margin.

Recommendation: Finally, the 1E-12 limit criterion was established following a review by different companies on the impact of the specific risk criteria. This impact included an evaluation of analytical workload versus benefit.

Comment: Given the location of this 1E-12 limit in the AC 9.b.(6) it should be made clear that the review of latent failures for multiple latent failure combinations is qualitative.

Recommendation: “Further when considering multiple latent failures the 1E-12 limit should be considered to define the scope of the qualitative evaluation to avoid latency. Typically such a review would not need to address quadruple redundancy or dual active – monitor designs etc.”

Comment (4):
Section 6.4.1.1.2 Change AC/AMC 25.629-1A, Section (c)(3)(c):
Comment: Previously the first sentence stated “However, the ASAWG decided not to consider adding a specific sentence to address active – active failure combinations.” This was a lead in to the next sentence. For example the second sentence refers to “redundancy in these situations”. However what situations are being referred to is no longer clear from the modified first sentence.

Recommendation: Add the word “other” to the first sentence. “However, the ASAWG decided not to consider other changes to FAR/CS 25.629…”

<u>Comment from Airbus:</u>

Consistency between AC/AMC 25.629 and FAR/CS 25.671 (c)(2) :

- AC/AMC 25.629 proposal : *"Any damage or failure conditions considered under FAR25.571, FAR25.631 and FAR25.671. The actuation system minimum requirements should also be continuously met after any combination of failures not shown to be extremely improbable ~~(occurrence less than 1E-09 per flight hour)~~. ~~However, certain combinations of failures, such as d~~ Loss of dual electric system or dual hydraulic systems are not normally considered extremely improbable.*
- FAR/CS 25.671 (c)(2) proposal : Any combination of failures not shown to be extremely improbable. Furthermore, the flight controls must comply with FAR25.1309(b)(4). This paragraph excludes failures of the type defined in (c)(3). ~~, excluding jamming (for example, dual electrical or hydraulic system failures, or any single failure in combination with any probable hydraulic or electrical failure).~~

On FAR25.671 proposal, examples of combination of failures non Extremely Improbable were removed whereas the same examples are kept in AC/AMC 25.629. What is the rational ? Why not to refer to FAR25.1309(b)(4) in both texts as follows :

- *"Any damage or failure conditions considered under FAR25.571, FAR25.631 and FAR25.671. The actuation system minimum requirements should also be continuously met after any combination of failures not shown to be extremely improbable ~~(occurrence less than 1E-09 per flight hour)~~. ~~However, certain combinations of failures, such as d Loss of dual electric system or dual hydraulic systems are not normally considered extremely improbable.~~ and under condition of FAR25.1309(b)(4).*

6.4.6 Appendix to Aging & Wear Task

None

6.4.7 Appendix to MMEL Task

6.4.7.1 MMEL Recommendation

The following provides discussions following the Cedar Rapids meeting where resolutions have been found but it was considered to be of value that these discussions be recorded.

Those discussions lead to tweak some wording in order to clarify the intent and get a consensus on the attached flowchart. Those discussions and agreement have been tracked through the issuance of an interim final report dated July 17, 2009.

In parallel, the same day , TCCA expressed mainly a concern on the use in the MMEL process of mitigation factors to alleviate and further proposed a change to the first box of the flowchart

Dassault Aviation requested clarifications on the proposed change to the flowchart. Following discussions with EASA and TCCA, Dassault Aviation was satisfied by their answers and cleared the proposed text (Extract from Dassault mail dated August 21 and 25, 2009).

Extract from
Dassault Aviation mai

During the meeting in March2010, consensus was reached between members to modify the body of the report based on Boeings latest proposal.

Boeing mail extract
06 Feb 10.doc

6.4.8 Appendix to Flight & Diversion Time Task

The following comments to chapter 6.4.4 were provided by Garmin. These general comments should be reviewed when preparing the final NRPM.

Comment (1):

Section 6.4.4.3 The Recommendations:

Comment: The terms specific risk and specific risk of concern are not used in the AC 25.1309.

Recommendation: Delete definitions.

Comment (2):

Section 6.4.1.6:

Comment: Can it be better clarified how the residual risk criterion is to be addressed. Perhaps include an example. It seems that the ASAWG is stating that the failure of the good engine (one without the pre-existing fault) cannot result in a condition that would cause the other engine fault to propagate to a failure (loss of engine or reduced thrust in icing conditions, WAT operations) that would be catastrophic. Similarly if engine with pre-existing fault encounters a condition that causes reduced thrust or engine failure prior to the good engine failure then is it assumed that the time between the first engine failure and landing the airplane can be applied as the exposure time to the good engine such that it will meet the residual risk?

Pratt & Whitney
400 Main Street
East Hartford, CT 06108

Pratt & Whitney
A United Technologies Company

October 22, 2010

Federal Aviation Administration
800 Independence Avenue, SW
Washington, D.C. 20591

Attention: Ms. Margaret Gilligan, Associate Administrator for Aviation Safety

Subject: Updated ARAC Recommendation, Avionics Systems Harmonization Working Group

References: 1. ARAC Tasking, Federal Register, April 23, 2002
2. TAEIG letter to FAA May 11, 2010

Dear Peggy,

The Transport Airplane and Engine Issues Group and the Avionics System Harmonization Working Group are pleased to submit the attached proposed new appendices to AC25-11A to the FAA as an updated ARAC recommendation. These proposed appendices address Weather Related Displays and Head-Up Displays in accordance with the reference 1 tasking. The Avionics HWG report was originally transmitted to the FAA per the reference 2 letter and included comments from Boeing and Bombardier. The working Group subsequently reviewed those comments and updated the proposed advisory material.

Sincerely yours,

Craig R. Bolt

C. R. Bolt
Assistant Chair, TAEIG

Copy: Mike Kaszycki – FAA-NWR
Clark Badie – Honeywell
James Wilborn – FAA-NWR
Suzanne Masterson – FAA NWR
Ralen Gao – FAA-Washington, D.C. – Office of Rulemaking

U.S. Department
of Transportation
**Federal Aviation
Administration**

DEC 17 2010

Mr. Craig R. Bolt, Assistant Chair
Aviation Rulemaking Advisory Committee
Pratt & Whitney
400 Main Street, Mail Stop 162-14
East Hartford, CT 06108

Dear Mr. Bolt:

This is in reply to your October 22, 2010 letter. Your letter transmitted to the FAA the Aviation Rulemaking Advisory Committee's (ARAC) updated recommendations regarding AC/AMC 25-11A for Weather Related Displays and Head-Up Displays (HUD). I understand this update is the result of the Avionics Systems Harmonization Working Group's (ASWHG) review of and response to Boeing and Bombardier's comments, attached to the original ARAC transmission in May 11, 2010.

I wish to thank the ARAC, particularly the members associated with TAEIG and its ASHWG that provided resources to develop the report and recommendation. The updated report will be placed on the ARAC website.

Sincerely,

Pamela Hamilton-Powell
Director, Office of Rulemaking

Appendix W
Weather Displays

1. Background and Scope:

This appendix provides additional guidance for displaying weather information in the flight deck. Weather displays provide the flight crew with additional tools to help the flight crew make decisions based on weather information.

Sources of weather information may include, but would not be limited to: onboard, real-time weather, data-linked weather, turbulence information, pilot/air traffic reports, and may be displayed in a variety of graphical or text formats.

Because there are many sources of weather information, it is important that the applicant identify and assess the intended function for a particular source and display of weather information, and apply the guidance contained within this AC/AMC.

2. Key Characteristics

In addition to the general guidelines provided in this AC, there are unique aspects of the display of weather information so that the information is being used as intended.

A. The display should enable the flight crew to quickly, accurately, and consistently differentiate among sources of displayed weather, as well as differentiate between time-critical weather information and dated, non-time critical weather information.

B. Weather presentations (display format, the use of colors, labels, data formats, and interaction with other display parameters) should be clear and unambiguous and not result in a flight crew member's misunderstanding or misinterpretation of the weather information being displayed. Weather displays may use red and amber/yellow provided that all of the following criteria are met;

1. The use of color is in compliance with 14 CFR/CS 25.1322, AC 25.1322, and this AC.
2. The use of color is appropriate to the task and context of use, and,
3. The proposed use does not affect the attention getting qualities of flight crew alerting and does not adversely affect the alerting functions across the flight deck, and,
4. Color conventions (such as ARINC 708; AC 20-149) are utilized.

Note: AC 20-149 indicates an exclusion to the acceptability of DO-267A (paragraph 7.d) for part 25 airplanes.

C. If more than one source of weather information is available to the flight crew, an indication of the weather source selection should be provided.

D. If weather information is displayed as an overlay on an existing display format, both the weather information and the information it overlays should be readily distinguished and correctly interpreted from each other. It also should be consistent with the information it overlays, in terms of position, orientation, range, and altitude.

E. When simultaneously displaying multiple weather sources (e.g. weather radar and data link weather), each source should be clear and unambiguous and not result in a misunderstanding or misinterpretation of the displayed weather information by the flight crew. This is applicable also for symbols (e.g. winds aloft, lightning) having the same meaning from different weather information sources.

F. Fusion of sensor information to create a single weather image may be acceptable provided the fused weather information meets its intended function, and the fused information is shown to be in compliance with the guidance in this AC (e.g the pilot understands the source of the fused information). When fusing or overlaying multiple weather sources, the resultant combined image should meet its intended function despite any differences in image quality, projection, data update rates, data latency, or sensor alignment algorithms.

G. If weather information is displayed on the HUD, the guidelines of this AC including appendix H need to be considered.

H. When weather is not displayed in real time, some means to identify its relevance (e.g. time stamp or product age) should be provided. Presenting product age is particularly important when combining information from multiple weather products.

I. If a weather radar looping (animation) feature is provided, means to readily identify the total elapsed time of the image compilation should be provided, to avoid potential misinterpretation of the movement of the weather cells.

J. For products that have the ability to present weather for varying altitudes (e.g., potential or reported icing, radar, lightning strikes), information should be presented that allows the flight crew to distinguish or identify which altitude range applies to each feature.

K. Weather information may include a number of graphical and text information "features" or sets of information (e.g. text and graphical METARS, winds aloft) There should be a means to identify the meaning of each "feature" to ensure that the information is correctly used.

L. If the pilot or system has the ability to turn a weather source on and off, there should be a clear means for the flight crew to determine if it is turned on or off.

M. When weather information is presented in a vertical situation display (VSD), it should be depicted sufficiently wide to contain the weather information that is relevant to the current phase of flight or flight path. In addition:

1. Weather information displayed on VSD shall be accurately depicted with respect to the scale factors of the display (i.e., vertical and horizontal), all vertical path information displayed, including glide slope, approach path, or angle of descent.
2. Consideration should be given to making the weather information display width consistent with the display width used by other systems, including Terrain Awareness and Warning System (TAWS), if displayed.

3. On-Board Weather Radar Information

On-Board Weather Radar may provide forward-looking weather detection, including windshear and turbulence detection.

The display of on-board weather radar information should be in accordance with the applicable portions of RTCA DO-220, "Minimum Operational Performance Standards for Airborne Weather Radar With Forward-Looking Windshear Capability."

The weather display echoes from precipitation and ground returns should be clear, automatic, timely, concise and distinct for rapid pilot interpretation so flight crews can easily analyze and avoid areas of detected hazards. The radar range, elevation, and azimuth indications should provide sufficient indication to the flight crew to allow for safe avoidance maneuvers.

4. Predictive Windshear Information

The display of windshear information, if provided, should be clear, automatic, timely, concise and distinct for rapid pilot interpretation so flight crews can easily detect and avoid areas of windshear activity.

When a windshear threat is detected, the corresponding display may be automatically presented or selected by pilot action, at a range which is appropriate to identify the windshear threat. Pilot workload necessary for its presentation should be minimized and should not take more than one action when the cockpit is configured for normal operating procedures.

The display of a predictive windshear threat, including relative position and azimuth with respect to the nose of the airplane, should be presented in an unambiguous manner to effectively assist the flight crew in responding to the windshear threat; the symbol should be presented in accordance with DO-220.

The size and location of the windshear threat should be presented using a symbol that is sufficient to allow the pilot to recognize and respond to the threat

The range selected by the pilot for the windshear display should be sufficient to allow the pilot to distinguish the event from other displayed information. Amber radial lines may be used to extend from the left and right radial boundaries of the icon extending to the upper edge of the display.

5. Safety Aspects

Both the loss of weather information plus the display of misleading weather information should be addressed in the functional hazard assessment (FHA). In particular, this should only address failures of the display system that could result in loss of or misleading weather information, not the sensor itself.

In accordance with paragraph 4 of this AC, display of misleading weather radar includes the display of weather radar information that would lead the pilot to make a bad decision and introduce a potential hazard. Examples of misleading weather radar information include, but are not limited to: storm cells presented on the display that are not in the correct position, are at the wrong intensity, not displayed when they should be displayed, or mis-registered in the case of a combined (e.g fused) image.

AC 25-11A Head-Up Display Appendix

1 INTRODUCTION

The material provided in this appendix provides additional guidance related to the unique aspects and characteristics, the design, analysis, testing, and definition of intended functions of head-up displays (HUD) for transport category airplanes.

In most applications, the HUD provides an indication of primary flight references which allow the pilot to rapidly evaluate the aircraft attitude, energy status, and position during the phases of flight for which the HUD is designed. A common objective of HUD information presentation is to enhance pilot performance in such areas as the transition between instrument and visual flight in variable outside visibility conditions. HUDs may be used to display enhanced and synthetic vision imagery, however the scope of this appendix does not include specific guidance for systems that provide this imagery.

This appendix addresses HUDs which are designed for a variety of different operational concepts and intended functions. It includes guidance for HUDs that are intended to be used as a supplemental display, where the HUD contains the minimum information immediately required for the operational task associated with the intended function. It also addresses HUDs that are intended to be used effectively as primary flight displays. This appendix addresses both the installation of a single HUD, typically for use by the left-side pilot, as well as special considerations related to the installation and use of dual HUDs, one for each pilot. These dual HUD special considerations will be called out in the appropriate sections which follow.

For guidance associated with specific operations using a HUD, such as low visibility approach and landing operations, see the relevant requirements and guidance material (e.g. CS-AWO, AC120-28D).

Additional guidance for the design and evaluation of HUDs can be found in ARP 5288, AS 8055 and ARP 5287.

2 HUD FUNCTION

The applicant is responsible for identifying the intended function of the HUD. The intended function should include the operational phases of flight, concept of operation, including how, when, and for what purpose the HUD is intended to be used. For example, the HUD systems may provide a head-up display of situational information and/or guidance information that may be used during all phases of flight.

2.1 Primary Flight Information

If the HUD is providing primary flight information, its primary flight information should be presented to allow easy recognition by the pilot while causing no confusion due to ambiguity with similar information presented on other aircraft flight deck displays.

If a HUD displays primary flight information, it is considered the de facto primary flight information while the pilot is using it, even if it is not the pilot's sole display of this information.

Primary flight information displayed on the HUD should comply with all the requirements associated with such information in Part 25 (e.g., §§ 25.1303(b) and 25.1333(b)). The requirements for arranging primary flight information are specified in § 25.1321(b). For specific guidance regarding the display of primary flight information see the main body of this AC and also Appendix 1.

2.2 Other Information

Other information displayed on a HUD may be dependent on the phases of flight and flight operations supported by the HUD. This additional information is mainly related to the display of command guidance or situational information.

For example, if the HUD is to be used to monitor the autopilot, the following information should be displayed:

a. Situation information based on independent raw data;
b. Autopilot operating mode;
c. Autopilot engage status;
c. Autopilot disconnect warning (visual).

Additional information should also be displayed if required to enable the pilot to perform aircraft maneuvers during phases of flight for which the HUD is approved. These may include:

a. Flight path indication;
b. Target airspeed references and speed limit indications;
c. Target altitude references and altitude awareness (e.g., DH, MDA) indications;
d. Heading or course references.

2.3 Head-Up to Head-Down Transition

Events that may lead to transition between the HUD and the Head Down Display (HDD) should be identified and scenarios developed for evaluation (e.g., simulation, flight test). These scenarios should include systems failures, as well as events leading to unusual attitudes. Transition capability should be shown for all foreseeable modes of upset.

There may be differences between the way in which the head up and head down displays present information (e.g., flight path, situational, or aircraft performance information). Differences between the head up format and head down format should not create pilot confusion, misinterpretation, unacceptable delay, or otherwise hinder the pilot's transition between the two displays. HUD information should be easy to recognize and interpret by the pilot while causing no confusion due to ambiguity with similar information presented on other aircraft flight deck displays.

The HUD symbols should be consistent, but not necessarily identical, with those used on head down instruments to prevent misinterpretation or difficulty in transitioning between the two types of display. Similar symbols on the HUD and on the head down displays should have the same meaning.

The use of similar symbols on the HUD and on the head down displays to represent different parameters is not acceptable.

2.4 Dual HUDs

The applicant should define the operational concept for the use of the dual-HUD installation that details Pilot-Flying/Pilot-Not-Flying (PF/PNF) tasks and responsibilities in regards to using and monitoring head-down displays (HDD) and HUD's during all phases of flight. The Dual HUD concept of operation should specifically address the simultaneous use of the HUD by both pilots during each phase of flight, as well as cross cockpit transfer of control.

Single HUD installations where the pilot is likely to use the HUD as a primary flight reference rely on the fact that the PNF will monitor the head-down instruments and alerting systems, for failures of systems, modes, and functions not associated with primary flight displays or HUD.

For the simultaneous use of dual HUDs, a means shall be provided so that the flight crew is able to maintain an equivalent level of awareness of key information not displayed on the HUD (e.g. powerplant indications, alerting messages, aircraft configuration indications).

The operational concept, defined by the applicant and used during the piloted evaluation of the installation, should account for the expected roles and responsibilities of the PF and the PNF, considering the following:

- When a pilot is using a HUD as the PFD, the visual head down indications may not receive the same level of vigilance by that pilot, compared to a pilot using the head down PFD.
- How the scan of the head down instruments is ensured during all phases of flight, and if not, what compensating design features are needed to help the flightcrew maintain awareness of key information (e.g., powerplant indications, alerting messages, aircraft configuration indication) not displayed on the HUD.
- Which pilot is expected to maintain a scan of head down instrument indications and how often. For any case where the scan of head down information is not full-time for at least one pilot, the design should have compensating design features which ensure an equivalent level of timeliness and awareness of the information provided by the head down visual indications.
- Cautions and warnings, if the visual information, equivalent to the head down PFD indications, is not presented in the HUD, the design should have compensating features that ensure the pilot using the HUD is made aware with no additional delay and able to respond with no reduction of task performance or degraded safety

For those phases of flight where airworthiness approval is predicated on the use of the HUD, or when it can be reasonably expected that the pilot will operate primarily by reference to the HUD, the objective is to not redirect attention of the pilot flying to another display when an immediate maneuver is required (e.g., resolution advisory, windshear). The applicant should either provide in the HUD the guidance, warnings, and annunciations of certain systems, if installed, such as a Terrain Awareness and Warning System (TAWS), or a traffic alert and collision avoidance system (TCAS) and a wind shear detection system, or provide compensating design features (e.g., a combinations of means such as control system protections and an unambiguous reversion message in the HUD) and procedures that ensure the pilot has equivalently effective visual information for timely awareness and satisfactory response to these alerts.

A global (re-)assessment of the alerting function should be performed to assess the HUDs alerting design and techniques together with the Alerting attention getting (visual MW and MC/aural) and other alerting information in the flight deck to ensure that timely crew awareness and response are always achieved when needed.

3 INSTALLATION

3.1 HUD Field of View

The design of the HUD installation should provide adequate display field-of-view in order for the HUD to function as intended in all anticipated flight attitudes, aircraft configurations, or environmental conditions, such as crosswinds, for which it is approved. All airworthiness and operational limitations should be specified in the AFM.

The optical characteristics of the HUD make the ability to fully view essential flight information more sensitive to the pilot's eye position, compared to head down displays. The HUD design eye-box is a three dimensional volume, specified by the manufacturer, within which display visibility requirements are met. For compliance to §§ 25.773 and 25.1301, whenever the pilot's eyes are within the design eyebox, the required flight information will be visible in the HUD. The minimum monocular field of view (FOV) required to display this required flight information, should include the center of the FOV and must be specified by the manufacturer.

The fundamental requirements for instrument arrangement and visibility that are found in §§ 25.1321, 25.773 and 25.777 apply to these devices. Section 25.1321 requires that each flight instrument for use by any pilot be plainly visible at that pilot's station, with minimum practicable deviation from the normal position and forward line of vision. Advisory Circular (AC) 25.773-1 defines the Design Eye Position (DEP) as a single point that meets the requirements of §§ 25.773 and 25.777. For certification purposes, the DEP is the pilot's normal seated position, and fixed markers or other means should be installed at each pilot station to enable the pilots to position themselves in their seats at the DEP for an optimum combination of outside visibility and instrument scan. The Design Eye Box should be positioned around the Design Eye Position.

The visibility of the displayed HUD symbols must not be unduly sensitive to pilot head movements in all expected flight conditions. In the event of a total loss of the display as a result of a head movement, the pilot must be able to regain the display rapidly and without difficulty.

The lateral and vertical dimensions of the eyebox represent the total movement of a monocular viewing instrument with a 1/4 in. (6.35 mm) entrance aperture (pupil). The eye-box longitudinal dimension represents the total fore-aft movement over which the requirement of this specification is met. (Reference SAE AS8055).

The HUD design eyebox should be laterally and vertically positioned around the respective pilot's design eye position (DEP), and be large enough that the required flight information will be visible to the pilot at the minimum displacements from the DEP listed below. When the HUD is a Primary Flight Display, or when airworthiness approval is predicated on the use of the HUD, or when the pilot can be reasonably expected to operate primarily by reference to the HUD, larger minimum design eyebox dimensions, than those shown below, may be necessary.

Lateral:	1.5 inches left and right from the DEP (three inches wide)
Vertical:	1.0 inches up and down from the DEP (two inches high)
Longitudinal:	2.0 inches fore and aft from the DEP (4 inches deep)

The HUD installation must comply with §§ 25.1321, 25.773 and accommodate pilots from 5'2" to 6'3" tall (per 25.777), seated with seat belts fastened and positioned at the DEP.

3.2 Obstruction of View

When installed, whether deployed or not, the HUD equipment must not create additional significant obstructions to either pilot's compartment view (§ 25.773). The equipment must not restrict either pilot's view of any controls, indicators or other flight instruments.

The HUD should not significantly degrade the necessary pilot compartment view of the outside world for normal, non-normal, or emergency flight maneuvers during any phase of flight for a pilot seated at the DEP. The HUD should be evaluated to ensure that it does not significantly affect the ability of any crewmember to spot other traffic, distinctly see approach lights, runways, signs, markings, or other aspects of the external visual scene.

The optical performance of the HUD must not degrade, distort or detract from the pilot's view of external references or in regards to seeing and avoiding other aircraft such that it would not enable them to safely perform any maneuvers within the operating limits of the airplane (§25.773). Where the windshield optically modifies the pilot's view of the outside world, the conformal HUD symbols must be optically consistent with the perceived outside view. The combination of the windshield and the HUD must meet the requirements of § 25.773(a)(1).

The optical qualities of the HUD should be uniform across the entire field of view. When viewed by both eyes from any off-center position within the eyebox, non-uniformities shall not produce perceivable differences in binocular view. Additional guidance is provided in ARP 5288.

3.3 Crew Safety

Installation of HUD equipment brings into consideration potential physical hazards not traditionally associated with head down electronic flight deck displays.

The HUD system must be designed and installed to prevent the possibility of pilot injury in the event of an accident or any other foreseeable circumstance such as turbulence, hard landing, bird strike, etc. The installation of the HUD, including overhead unit and combiner, must comply with the head injury criteria (HIC) of § 25.562 (c)(5). Additionally, the HUD installation must comply with the retention requirements of § 25.789(a) and occupant injury requirements of §§ 25.785 (d) and (k).

For a dual HUD installation, there is the potential for both pilots to experience an incapacitating injury as a result of flight or gust loads. This becomes a safety of flight issue, since the entire flightcrew would be incapacitated. The types of injuries of concern may be long duration, low impact, high load, as opposed to the high impact, short duration injuries assessed by HIC. A dedicated method of compliance may be needed should analysis of the installation geometry indicate that flight or gust loads will produce occupant contact with the HUD installation.

For compliance to §§ 25.803, 25.1307, 25.1411 and 25.1447, the HUD installation must not interfere with or restrict the use of other installed equipment such as emergency oxygen masks, headsets, or microphones. The installation of the HUD must not adversely affect the emergency egress provisions for the flight crew, or significantly interfere with crew access. The system must not hinder the crew's movement while conducting any flight procedures.

3.4 HUD Controls

For compliance to § 25.777, the means of controlling the HUD, including its configuration and display modes, must be visible to, identifiable, accessible, and within the reach of, the pilots from their normal seated position. For compliance to §§ 25.777, 25.789 and 25.1301, the position and movement of the HUD controls must not lead to inadvertent operation. For compliance to § 25.1381, the HUD controls must be adequately illuminated for all normal ambient lighting conditions, and must not create any objectionable reflections on the HUD or other flight instruments. Unless a fixed level of illumination is satisfactory under all lighting conditions, there should be a means to control its intensity.

To the greatest extent practicable, the HUD controls should be integrated with other associated flight deck controls, to minimize the crew workload associated with HUD operation and to enable flightcrew awareness.

HUD controls, including the controls to change or select HUD modes, should be implemented to minimize pilot workload for data selection or data entry and allow the pilot to easily view and perform all mode control selections from his seated position.

4 INFORMATION PRESENTATION

4.1 Displayed Information

The HUD information display requirements will depend on the intended function of the HUD. Specific guidance for displayed information is contained within the main body and Appendix 1 of this AC. In addition, the following sections provide guidance related to unique characteristics of the HUD. As in the case of other flight deck displays, new and/or novel display formats may be subject to an Authority human factors pilot interface evaluation(s).

4.1.1 Alternate Formats of Displaying Primary Flight Information

There may be certain operations and phases of flight during which certain primary flight reference indications in the HUD do not need to have the analog cues for trend, deviation, and quick glance awareness that would normally be necessary. For example, during the precision approach phase, HUD formats have been accepted that provide a digital only display of airspeed and altitude. Acceptance of these displays has been predicated on the availability of compensating features that provide clear and distinct warning to the flight crew when these and certain other parameters exceed well-defined tolerances around the nominal approach state (e.g., approach warning), and these warnings have associated procedures that require the termination of the approach.

Formats with digital-only display of primary flight information (e.g., airspeed, altitude, attitude, heading) should be demonstrated to provide at least:

- a satisfactory level of task performance,
- a satisfactory awareness of proximity to limit values, like Vs, VMO and VFE, or
- a satisfactory means to avoid violating such limits.

If a different display format is used for go-around than that used for the approach, the format transition should occur automatically as a result of the normal go-around or missed approach procedure.

Changes in the display format and primary flight data arrangement should be minimized to prevent confusion and to enhance the pilots' ability to interpret vital data.

4.1.2 Aircraft Control Considerations

For those phases of flight where airworthiness approval is predicated on the use of the HUD, or when it can be reasonably expected that the pilot will operate primarily by reference to the HUD, the HUD should adequately provide:

- information to permit instant pilot evaluation of the airplane's flight state and position. This should be shown to be adequate for manually controlling the airplane, and for monitoring the performance of the automatic flight control system. Use of the HUD for manual control of the airplane and monitoring of the automatic flight control system, should not require exceptional skill, excessive workload, or excessive reference to other flight displays.

- cues for the pilot to instantly recognize unusual attitudes and shall not hinder its recovery. If the HUD is designed to provide guidance or information for recovery from upsets or unusual attitudes, recovery steering guidance commands should be distinct from, and not confused with, orientation symbology such as horizon "pointers." This capability should be shown for all foreseeable modes of upset, including crew mishandling, autopilot failure (including "slowovers"), and turbulence/gust encounters.

4.1.3 Airspeed Considerations

As with other electronic flight displays, the HUD airspeed indications may not typically show the entire range of airspeed. Section 25.1541 (b)(2) of the Federal Aviation Regulations states: "The airplane must contain - Any additional information, instrument markings, and placards required for the safe operation if there are unusual design, operating, or handling characteristics. "

Low speed awareness cues presented on the HUD should provide adequate visual cues to the pilot that the airspeed is below the reference operating speed for the airplane configuration (i.e., weight, flap setting, landing gear position, etc.); similarly, high speed awareness cues should provide adequate visual cues to the pilot that the airspeed is approaching an established upper limit that may result in a hazardous operating condition.

The cues should be readily distinguishable from other markings such as V-speeds and speed targets (bugs). The cues should not only indicate the boundary value of speed limit, but also clearly distinguish between the normal speed range and the unsafe speed range beyond those limiting values. Cross-hatching may be acceptable to provide delineation between zones of different meaning.

4.1.4 Flight Path Considerations

An indication of the aircraft's velocity vector, or flight path vector, is considered essential to most HUD applications. Earth-referenced flight path display information provides an instantaneous indication of where the aircraft is actually going. During an approach this information can be used to indicate the aircraft's impact or touchdown point on the runway. The earth referenced flight path will show the effects of wind on the motion of the airplane. The flight path vector can be used by the pilot to set a precise climb or dive angle relative to the conformal outside scene or relative to the HUD's flight path (pitch) reference scale and horizon displays. In the lateral axis the flight path symbols should indicate the aircraft track relative to the boresight.

Air mass derived flight path may be displayed as an alternative, but will not show the effects of wind on the motion of the airplane. In this case the lateral orientation of the flight path display represents the aircraft's sideslip while the vertical position relative to the reference symbol represents the aircraft's angle of attack.

The type of flight path information displayed (e.g., earth referenced, air mass) may be dependent on the operational characteristics of a particular aircraft and the phase of flight during which the flight path is to be displayed.

4.1.5 Attitude Considerations

An accurate, easy, quick glance interpretation of attitude by the pilot should be possible for all unusual attitude situations and command guidance display configurations. The pitch attitude display should be such that during all maneuvers a horizon reference remains visible with enough margin to allow the pilot to recognize pitch and roll orientation. For HUDs that are capable of displaying the horizon conformally, display of a non-conformal horizon reference should be distinctly different than the display of a conformal horizon reference.

In addition, extreme attitude symbology and automatically decluttering the HUD at extreme attitudes has been found acceptable (extreme attitude symbology should not be visible during normal maneuvering).

When the HUD is designed not to be used for recovery from unusual attitude, there should be:

- compensating features (e.g., characteristics of the airplane and the HUD system),
- immediate direction to the pilot to use the head down PFD for recovery, and
- satisfactory demonstration of timely recognition and correct recovery maneuvers.

4.2 Display Compatibility

The content, arrangement and format of the HUD information should be sufficiently compatible and consistent with the head down displays to preclude pilot confusion, misinterpretation, or excessive cognitive workload. Transitions between the HUD and head down displays, whether required by navigation duties, failure conditions, unusual airplane attitudes, or other reasons, should not present difficulties in data interpretation or delays/interruptions in the flight crew's ability to manually control the airplane or to monitor the automatic flight control system.

The HUD and HDD formats and data sources need to be compatible to ensure that the same information presented on both displays have the same intended meaning. HUD and HDD parameters should be consistent to avoid misinterpretation of similar information, but the display presentations need not be identical.

Deviation from these guidelines may be unavoidable due to conflict with other information display characteristics or requirements unique to head up displays. These may include minimization of display clutter, minimization of excessive symbol flashing, and the presentation of certain information conformal to the outside scene. Deviations from these guidelines will require additional pilot evaluation.

The following should be considered:

(a) Symbols that have the same meaning should be the same format;

(b) Information (symbols) should appear in the same general location relative to other information;

(c) Alphanumeric readouts should have the same resolution, units, and labeling (e.g., the command reference indication for "vertical speed" should be displayed in the same foot-per-minute increments and labeled with the same characters as the head-down displays);

(d) Analogue scales or dials should have the same range and dynamic operation (e.g., a Glideslope Deviation Scale displayed head-up should have the same displayed range as the Glideslope Deviation Scale displayed head-down, and the direction of movement should be consistent);

(e) FGS modes (e.g. autopilot, flight director, autothrust) and state transitions (e.g. land 2 to land 3) should be displayed on the HUD, and except for the use of colour, should be displayed using consistent methods (e.g., the method used head-down to indicate a flight director mode transitioning from armed to captured should also be used head-up); and

(f) Information sources should be consistent between the HUD and the head-down displays used by the same pilot.

(g) When command information (i.e., flight director commands) is displayed on the HUD in addition to the head-down displays, the HUD depiction and guidance cue deviation "scaling" needs to be consistent with that used on the head-down displays. This is intended to provide comparable pilot performance and workload when using either head-up or head-down displays.

(h) The unique information concerning current HUD system mode, reference data, status state transitions, and alert information that is displayed to the pilot flying on the HUD, should also be displayed to the pilot not flying using consistent nomenclature to ensure unambiguous awareness of the HUD operation.

4.3 Indications and Alerts

In order to demonstrate compliance with 25.1322 and to the extent that most HUDs are currently single color (monochrome) devices, caution and warning information should be emphasized with the appropriate use of attention-getting properties such as flashing, outline boxes, brightness, size, and/or location to compensate for the lack of color coding. A consistent documented philosophy should be developed for each alert level and conflicts of meaning with head-down display format changes will need to be avoided.

Additional guidance is in AC 25.1329 and AC 25.1322 and the associated regulations.

4.4 Display Clutter

Clutter has been addressed elsewhere in this A(M)C. However, for a HUD, special attention is needed regarding the effects of clutter affecting the see-through characteristics of the display.

5 VISUAL CHARACTERISTICS

The following paragraphs highlight some areas, which are related to performance aspects that are specific to the HUD. ARP5288 and AS8055 provide performance guidelines for a head-up display. As stated in Chapter 3, the applicant should notify the Airworthiness Authority if any visual display characteristics do not meet the guidelines in AS8055 and ARP 5288.

5.1 Luminance Control

The display luminance (brightness) should be satisfactory in the presence of dynamically changing background (ambient) lighting conditions (0 to 10,000 fL per AS8055), so that the HUD data is visible to the pilot(s). To accomplish this, the HUD may have both manual and automatic luminance control capabilities. It is recommended that automatic control is provided in addition to the manual control. Manual control of the HUD brightness level should be available to the flight crew in order to provide the means to set a reference level for automatic brightness control. If automatic control for display brightness is not provided, it should be shown that a single manual setting is satisfactory for the range of lighting conditions encountered during all foreseeable operational conditions and against expected external scenes. Readability of the displays should be satisfactory in all foreseeable operating and ambient lighting conditions. AS8055 and ARP 5288 provide guidelines for contrast and luminance control.

5.2 Alignment

Proper HUD alignment is needed to match conformal display parameters as close as possible to the outside (real) world, depending on the intended function of those parameters.

If the HUD combiner is stowable, means should be provided to ensure that it is fully deployed prior to using the symbology for aircraft control. The HUD system shall provide means to alert the pilot if the position of the combiner causes normally conformal data to become misaligned in a manner that may result in display of misleading information.

The range of motion of conformal symbology can present certain challenges in rapidly changing and high crosswind conditions. In certain cases, the motion of the guidance and the primary reference cue may be limited by the field of view.

It should be shown that, in such cases, the guidance remains usable and that there is a positive indication that it is no longer conformal with the outside scene. It should also be shown that there is no interference between the indications of primary flight information and the flight guidance cues.

5.2.1 Symbol Positioning Accuracy (External)

External Symbol Positioning Accuracy, or Display Accuracy, is a measure of the relative conformality of the HUD display with respect to the real world view seen by the pilot through the combiner and windshield from any eye position within the HUD Eyebox. Display Accuracy is a monocular measurement, and, for a fixed field point, is numerically equal to the angular difference between the position of a real world feature as seen through the combiner and windshield, and the HUD projected symbology.

The total HUD system display accuracy error budget (excluding sensor and windshield errors) includes installation errors, digitization errors, electronic gain and offset errors, optical errors, combiner positioning errors, errors associated with the CRT and yoke (if applicable), misalignment errors, environmental conditions (i.e., temperature and vibration), and component variations. Optical errors are both head position and field angle dependent and are comprised of three sources: uncompensated pupil and field errors originating in the optical system aberrations, image distortion errors, and manufacturing variations. The optical errors are statistically determined by sampling the HUD FOV and Eyebox. (See 4.2.10 of SAE 8055 for a discussion of field of view and Eyebox sampling);

- The optical errors shall represent 95.4% (2 sigma) of all sampled points.
- The display accuracy errors are characterized in both the horizontal and vertical planes.
- Total display accuracy shall be characterized as the root-sum square (RSS) errors of these two component errors.

All display errors shall be minimized across the display field of view consistent with the intended function of the HUD. The following are the allowable display accuracy errors for a conformal HUD as measured from the HUD Eye Reference Point:

- HUD Boresight <= 5.0 mrad
- <= 10° diameter <= 7.5 mrad (2 Sigma)
- <= 30° diameter <=10.0 mrad (2 Sigma)
- >30° diameter < 10 mrad + kr[(FOV)(in degrees) - 30)] (2 Sigma)
  kr = 0.2 mrad of error per degree of FOV

The HUD manufacturer shall specify the maximum allowable installation error. In no case shall the display accuracy error tolerances cause hazardously misleading data to be presented to the pilot viewing the HUD.

5.2.2 Symbol Positioning Alignment

Symbols which are interpreted relative to each other shall be aligned to preclude erroneous interpretation of information. Symbols which are not interpreted relative to each other may overlap but shall not cause erroneous interpretation of display data, even when they overlap.

5.2.3 Combiner Position Alignment:

The HUD system shall provide a warning to the pilot if the position of the combiner causes conformal data to become hazardously misaligned.

5.3 Reflections and Glare

The HUD must be free of glare and reflections that could interfere with the normal duties of the minimum flight crew (per 14 CFR 25.1523 and 25.777).

5.4 Ghost Images

The visibility of ghost images within the HUD of external surfaces must be minimized so as not to impair the pilot's ability to use the display.

A ghost image is an undesired image appearing at the image plane of an optical system. Reflected light may form an image near the plane of the primary image. This may result in a false image of the object or an out-of-focus image of a bright source of light in the field of the optical system (e.g., a "ghost image").

5.5 Design Eye Position

The HUD Design Eye Position (DEP) must be the same as that defined for the basic cockpit in accordance with AC 25.773-1. The Design Eyebox must contain the DEP. The displayed symbols which are necessary to perform the required tasks must be visible to the pilot from the DEP and the symbols must be positioned such that excessive eye movements are not required to scan elements of the display.

5.6 Field Of View

The Field of View should be established by taking into consideration the intended operational environment and potential aircraft configurations.

5.7 Head Motion

The visibility of the displayed symbols must not be unduly sensitive to pilot head movements in all expected flight conditions. In the event of a total loss of the display as a result of a head movement, the pilot must be able to regain the display rapidly and without difficulty.

5.8 Accuracy and Stability

The system operation should not be adversely affected by aircraft manoeuvring or changes in attitude encountered in normal service.
The accuracy of positioning of symbols must be commensurate with their intended use. Motion of non-conformal symbols must be smooth, not sluggish or jerky, and consistent with aircraft control response. Symbols must be stable with no discernible flicker or jitter.

5.9 HUD Optical Performance

As far as practicable, the optical performance of the HUD must not degrade, distort or detract from the pilot's view of external references or of other aircraft. Where the windshield optically modifies the pilot's view of the outside world, the conformal HUD symbols must be optically consistent with the perceived outside view. The combination of the windshield and the HUD must meet the requirements of 14 CFR/CS 25.773(a)(1).

6 SAFETY ASPECTS

The installation of HUD systems in flight decks may introduce complex functional interrelationships between the pilots and other display and control systems. Consequently, a Functional Hazard Assessment (FHA) which requires a top down approach, from an airplane level perspective, should be developed in accordance with FAR/CS 25.1309. Development of a FHA for a particular installation requires careful consideration of the role the HUD plays within the flight deck in terms of integrity of function and availability of function, as well the operational concept of the installation to be certified (dual vs single, type and amount of information displayed, etc.). Chapter 4 of this AC provides material that may be useful in supporting the FHA preparation.

All alleviating flight crew actions that are considered in the HUD safety analysis need to be validated for incorporation in the airplane flight manual procedures section or for inclusion in type-specific training.

Since the flight information displayed on the HUD is visible only to one pilot, and since in most cases, failures of flight parameters shown on the HUD are not independent of those shown on the same pilot's head down primary flight display, the *applicant should demonstrate that* the HUD only provides a suitable means to comply with 25.1333(b) following loss of primary head down flight display to the pilot using the HUD. The rule requires that at least one display of information essential to safety of flight remain available to the (both) pilots, not just one pilot.

7 CONTINUED AIRWORTHINESS

Depending on the type of operation and the intended function of the HUD, instructions for the continued airworthiness of a display system and its components have to be prepared to show compliance with §§ 25.1309 and 25.1529 (including Appendix H)

8 FLIGHT DATA RECORDING

The installation of HUDs has design aspects and unique operational characteristics requiring specific accident recording considerations. HUD guidance modes and status (in use or inoperative) and display declutter mode should be considered to be recorded to comply with § 25.1459(e) and 121.344.

Appendix W
Weather Displays

1. Background and Scope:

This appendix provides additional guidance for displaying weather information in the flight deck. Weather displays provide the flight crew with additional tools to help the flight crew make decisions based on weather information.

Sources of weather information may include, but would not be limited to: onboard, real-time weather, data-linked weather, turbulence information, pilot/air traffic reports, and may be displayed in a variety of graphical or text formats.

Because there are many sources of weather information, it is important that the applicant identify and assess the intended function for a particular source and display of weather information, and apply the guidance contained within this AC/AMC.

2. Key Characteristics

In addition to the general guidelines provided in this AC, there are unique aspects of the display of weather information so that the information is being used as intended.

A. The display should enable the flight crew to quickly, accurately, and consistently differentiate among sources of displayed weather, as well as differentiate between time-critical weather information and dated, non-time critical weather information.

B. Weather presentations (display format, the use of colors, labels, data formats, and interaction with other display parameters) should be clear and unambiguous and not result in a flight crew member's misunderstanding or misinterpretation of the weather information being displayed. Weather displays may use red and amber/yellow provided that all of the following criteria are met;

1. The use of color is in compliance with 14 CFR/CS 25.1322, AC 25.1322, and this AC.
2. The use of color is appropriate to the task and context of use, and,
3. The proposed use does not affect the attention getting qualities of flight crew alerting and does not adversely affect the alerting functions across the flight deck, and,
4. Color conventions (such as ARINC 708; AC 20-149) are utilized.

Note: AC 20-149 indicates an exclusion to the acceptability of DO-267A (paragraph 7.d) for part 25 airplanes.

C. If more than one source of weather information is available to the flight crew, an indication of the weather source selection should be provided.

D. If weather information is displayed as an overlay on an existing display format, both the weather information and the information it overlays should be readily distinguished and correctly interpreted from each other. It also should be consistent with the information it overlays, in terms of position, orientation, range, and altitude.

E. When simultaneously displaying multiple weather sources (e.g. weather radar and data link weather), each source should be clear and unambiguous and not result in a misunderstanding or misinterpretation of the displayed weather information by the flight crew. This is applicable also for symbols (e.g. winds aloft, lightning) having the same meaning from different weather information sources.

F. Fusion of sensor information to create a single weather image may be acceptable provided the fused weather information meets its intended function, and the fused information is shown to be in compliance with the guidance in this AC (e.g the pilot understands the source of the fused information). When fusing or overlaying multiple weather sources, the resultant combined image should meet its intended function despite any differences in image quality, projection, data update rates, data latency, or sensor alignment algorithms.

G. If weather information is displayed on the HUD, the guidelines of this AC including appendix H need to be considered.

H. When weather is not displayed in real time, some means to identify its relevance (e.g. time stamp or product age) should be provided. Presenting product age is particularly important when combining information from multiple weather products.

I. If a weather radar looping (animation) feature is provided, means to readily identify the total elapsed time of the image compilation should be provided, to avoid potential misinterpretation of the movement of the weather cells.

J. For products that have the ability to present weather for varying altitudes (e.g., potential or reported icing, radar, lightning strikes), information should be presented that allows the flight crew to distinguish or identify which altitude range applies to each feature.

Deleted: s are being presented.

K. Weather information may include a number of graphical and text information "features" or sets of information (e.g. text and graphical METARS, winds aloft) There should be a means to identify the meaning of each "feature" to ensure that the information is correctly used.

Deleted: ¶

L. If the pilot or system has the ability to turn a weather source on and off, there should be a clear means for the flight crew to determine if it is turned on or off.

M. When weather information is presented in a vertical situation display (VSD), it should be depicted sufficiently wide to contain the weather information that is relevant to the current phase of flight or flight path. In addition:

1. Weather information displayed on VSD shall be accurately depicted with respect to the scale factors of the display (i.e., vertical and horizontal), all vertical path information displayed, including glide slope, approach path, or angle of descent.
2. Consideration should be given to making the weather information display width consistent with the display width used by other systems, including Terrain Awareness and Warning System (TAWS), if displayed.

3. On-Board Weather Radar Information

On-Board Weather Radar may provide forward-looking weather detection, including windshear and turbulence detection.

The display of on-board weather radar information should be in accordance with the applicable portions of RTCA DO-220, "Minimum Operational Performance Standards for Airborne Weather Radar With Forward-Looking Windshear Capability."

The weather display echoes from precipitation and ground returns should be clear, automatic, timely, concise and distinct for rapid pilot interpretation so flight crews can easily analyze and avoid areas of detected hazards. The radar range, elevation, and azimuth indications should provide sufficient indication to the flight crew to allow for safe avoidance maneuvers.

4. Predictive Windshear Information

The display of windshear information, if provided, should be clear, automatic, timely, concise and distinct for rapid pilot interpretation so flight crews can easily detect and avoid areas of windshear activity.

When a windshear threat is detected, the corresponding display may be automatically presented or selected by pilot action, at a range which is appropriate to identify the windshear threat. Pilot workload necessary for its presentation should be minimized and should not take more than one action when the cockpit is configured for normal operating procedures.

The display of a predictive windshear threat, including relative position and azimuth with respect to the nose of the airplane, should be presented in an unambiguous manner to effectively assist the flight crew in responding to the windshear threat; the symbol should be presented in accordance with DO-220.

The size and location of the windshear threat should be presented using a symbol that is sufficient to allow the pilot to recognize and respond to the threat

The range selected by the pilot for the windshear display should be sufficient to allow the pilot to distinguish the event from other displayed information. Amber radial lines may be used to extend from the left and right radial boundaries of the icon extending to the upper edge of the display.

5. Safety Aspects

Both the loss of weather information plus the display of misleading weather information should be addressed in the functional hazard assessment (FHA). In particular, this should only address failures of the display system that could result in loss of or misleading weather information, not the sensor itself.

In accordance with paragraph 4 of this AC, display of misleading weather radar includes the display of weather radar information that would lead the pilot to make a bad decision and introduce a potential hazard. Examples of misleading weather radar information include, but are not limited to: storm cells presented on the display that are not in the correct position, are at the wrong intensity, not displayed when they should be displayed, or mis-registered in the case of a combined (e.g fused) image.

AC 25-11A Head-Up Display Appendix

1 INTRODUCTION

The material provided in this appendix provides additional guidance related to the unique aspects and characteristics, the design, analysis, testing, and definition of intended functions of head-up displays (HUD) for transport category airplanes.

In most applications, the HUD provides an indication of primary flight references which allow the pilot to rapidly evaluate the aircraft attitude, energy status, and position during the phases of flight for which the HUD is designed. A common objective of HUD information presentation is to enhance pilot performance in such areas as the transition between instrument and visual flight in variable outside visibility conditions. HUDs may be used to display enhanced and synthetic vision imagery, however the scope of this appendix does not include specific guidance for systems that provide this imagery.

This appendix addresses HUDs which are designed for a variety of different operational concepts and intended functions. It includes guidance for HUDs that are intended to be used as a supplemental display, where the HUD contains the minimum information immediately required for the operational task associated with the intended function. It also addresses HUDs that are intended to be used effectively as primary flight displays. This appendix addresses both the installation of a single HUD, typically for use by the left-side pilot, as well as special considerations related to the installation and use of dual HUDs, one for each pilot. These dual HUD special considerations will be called out in the appropriate sections which follow.

For guidance associated with specific operations using a HUD, such as low visibility approach and landing operations, see the relevant requirements and guidance material (e.g. CS-AWO, AC120-28D).

Additional guidance for the design and evaluation of HUDs can be found in ARP 5288, AS 8055 and ARP 5287.

2 HUD FUNCTION

The applicant is responsible for identifying the intended function of the HUD. The intended function should include the operational phases of flight, concept of operation, including how, when, and for what purpose the HUD is intended to be used. For example, the HUD systems may provide a head-up display of situational information and/or guidance information that may be used during all phases of flight.

2.1 Primary Flight Information

If the HUD is providing primary flight information, its primary flight information should be presented to allow easy recognition by the pilot while causing no confusion due to ambiguity with similar information presented on other aircraft flight deck displays.

If a HUD displays primary flight information, it is considered the de facto primary flight information while the pilot is using it, even if it is not the pilot's sole display of this information.

Primary flight information displayed on the HUD should comply with all the requirements associated with such information in Part 25 (e.g., §§ 25.1303(b) and 25.1333(b)). The requirements for arranging primary flight information are specified in § 25.1321(b). For specific guidance regarding the display of primary flight information see the main body of this AC and also Appendix 1.

2.2 Other Information

Other information displayed on a HUD may be dependent on the phases of flight and flight operations supported by the HUD. This additional information is mainly related to the display of command guidance or situational information.

For example, if the HUD is to be used to monitor the autopilot, the following information should be displayed:

a. Situation information based on independent raw data;
b. Autopilot operating mode;
c. Autopilot engage status;
c. Autopilot disconnect warning (visual).

Additional information should also be displayed if required to enable the pilot to perform aircraft maneuvers during phases of flight for which the HUD is approved. These may include:

a. Flight path indication;
b. Target airspeed references and speed limit indications;
c. Target altitude references and altitude awareness (e.g., DH, MDA) indications;
d. Heading or course references.

2.3 Head-Up to Head-Down Transition

Events that may lead to transition between the HUD and the Head Down Display (HDD) should be identified and scenarios developed for evaluation (e.g., simulation, flight test). These scenarios should include systems failures, as well as events leading to unusual attitudes. Transition capability should be shown for all foreseeable modes of upset.

There may be differences between the way in which the head up and head down displays present information (e.g., flight path, situational, or aircraft performance information). Differences between the head up format and head down format should not create pilot confusion, misinterpretation, unacceptable delay, or otherwise hinder the pilot's transition between the two displays. HUD information should be easy to recognize and interpret by the pilot while causing no confusion due to ambiguity with similar information presented on other aircraft flight deck displays.

The HUD symbols should be consistent, but not necessarily identical, with those used on head down instruments to prevent misinterpretation or difficulty in transitioning between the two types of display. Similar symbols on the HUD and on the head down displays should have the same meaning.

The use of similar symbols on the HUD and on the head down displays to represent different parameters is not acceptable.

2.4 Dual HUDs

The applicant should define the operational concept for the use of the dual-HUD installation that details Pilot-Flying/Pilot-Not-Flying (PF/PNF) tasks and responsibilities in regards to using and monitoring head-down displays (HDD) and HUD's during all phases of flight. The Dual HUD concept of operation should specifically address the simultaneous use of the HUD by both pilots during each phase of flight, as well as cross cockpit transfer of control.

Single HUD installations where the pilot is likely to use the HUD as a primary flight reference rely on the fact that the PNF will monitor the head-down instruments and alerting systems, for failures of systems, modes, and functions not associated with primary flight displays or HUD.

For the simultaneous use of dual HUDs, a means shall be provided so that the flight crew is able to maintain an equivalent level of awareness of key information not displayed on the HUD (e.g. powerplant indications, alerting messages, aircraft configuration indications).

The operational concept, defined by the applicant and used during the piloted evaluation of the installation, should account for the expected roles and responsibilities of the PF and the PNF, considering the following:

- When a pilot is using a HUD as the PFD, the visual head down indications may not receive the same level of vigilance by that pilot, compared to a pilot using the head down PFD.
- How the scan of the head down instruments is ensured during all phases of flight, and if not, what compensating design features are needed to help the flightcrew maintain awareness of key information (e.g., powerplant indications, alerting messages, aircraft configuration indication) not displayed on the HUD.
- Which pilot is expected to maintain a scan of head down instrument indications and how often. For any case where the scan of head down information is not full-time for at least one pilot, the design should have compensating design features which ensure an equivalent level of timeliness and awareness of the information provided by the head down visual indications.
- Cautions and warnings, if the visual information, equivalent to the head down PFD indications, is not presented in the HUD, the design should have compensating features that ensure the pilot using the HUD is made aware with no additional delay and able to respond with no reduction of task performance or degraded safety

For those phases of flight where airworthiness approval is predicated on the use of the HUD, or when it can be reasonably expected that the pilot will operate primarily by reference to the HUD, the objective is to not redirect attention of the pilot flying to another display when an immediate maneuver is required (e.g., resolution advisory, windshear). The applicant should either provide in the HUD the guidance, warnings, and annunciations of certain systems, if installed, such as a Terrain Awareness and Warning System (TAWS), or a traffic alert and collision avoidance system (TCAS) and a wind shear detection system, or provide compensating design features (e.g., a combinations of means such as control system protections and an unambiguous reversion message in the HUD) and procedures that ensure the pilot has equivalently effective visual information for timely awareness and satisfactory response to these alerts.

A global (re-)assessment of the alerting function should be performed to assess the HUDs alerting design and techniques together with the Alerting attention getting (visual MW and MC/aural) and other alerting information in the flight deck to ensure that timely crew awareness and response are always achieved when needed.

Comment [H1]: Per feedback received during the TAEIG report, PNF will have other duties including reviewing checklist, performing communications, etc, and will not monitor "full time"

Deleted: ,

Deleted: full-time

Deleted: ,

Deleted: the applicant should demonstrate

3 INSTALLATION

3.1 HUD Field of View

The design of the HUD installation should provide adequate display field-of-view in order for the HUD to function as intended in all anticipated flight attitudes, aircraft configurations, or environmental conditions, such as crosswinds, for which it is approved. All airworthiness and operational limitations should be specified in the AFM.

The optical characteristics of the HUD make the ability to fully view essential flight information more sensitive to the pilot's eye position, compared to head down displays. The HUD design eye-box is a three dimensional volume, specified by the manufacturer, within which display visibility requirements are met. For compliance to §§ 25.773 and 25.1301, whenever the pilot's eyes are within the design eyebox, the required flight information will be visible in the HUD. The minimum monocular field of view (FOV) required to display this required flight information, should include the center of the FOV and must be specified by the manufacturer.

The fundamental requirements for instrument arrangement and visibility that are found in §§ 25.1321, 25.773 and 25.777 apply to these devices. Section 25.1321 requires that each flight instrument for use by any pilot be plainly visible at that pilot's station, with minimum practicable deviation from the normal position and forward line of vision. Advisory Circular (AC) 25.773-1 defines the Design Eye Position (DEP) as a single point that meets the requirements of §§ 25.773 and 25.777. For certification purposes, the DEP is the pilot's normal seated position, and fixed markers or other means should be installed at each pilot station to enable the pilots to position themselves in their seats at the DEP for an optimum combination of outside visibility and instrument scan. The Design Eye Box should be positioned around the Design Eye Position.

The visibility of the displayed HUD symbols must not be unduly sensitive to pilot head movements in all expected flight conditions. In the event of a total loss of the display as a result of a head movement, the pilot must be able to regain the display rapidly and without difficulty.

The lateral and vertical dimensions of the eyebox represent the total movement of a monocular viewing instrument with a 1/4 in. (6.35 mm) entrance aperture (pupil). The eye-box longitudinal dimension represents the total fore-aft movement over which the requirement of this specification is met. (Reference SAE AS8055).

The HUD design eyebox should be laterally and vertically positioned around the respective pilot's design eye position (DEP), and be large enough that the required flight information will be visible to the pilot at the minimum displacements from the DEP listed below. When the HUD is a Primary Flight Display, or when airworthiness approval is predicated on the use of the HUD, or when the pilot can be reasonably expected to operate primarily by reference to the HUD, larger minimum design eyebox dimensions, than those shown below, may be necessary.

Lateral:	1.5 inches left and right from the DEP (three inches wide)
Vertical:	1.0 inches up and down from the DEP (two inches high)
Longitudinal:	2.0 inches fore and aft from the DEP (4 inches deep)

The HUD installation must comply with §§ 25.1321, 25.773 and accommodate pilots from 5'2" to 6'3" tall (per 25.777), seated with seat belts fastened and positioned at the DEP.

3.2 Obstruction of View

When installed, whether deployed or not, the HUD equipment must not create additional significant obstructions to either pilot's compartment view (§ 25.773). The equipment must not restrict either pilot's view of any controls, indicators or other flight instruments.

The HUD should not significantly degrade the necessary pilot compartment view of the outside world for normal, non-normal, or emergency flight maneuvers during any phase of flight for a pilot seated at the DEP. The HUD should be evaluated to ensure that it does not significantly affect the ability of any crewmember to spot other traffic, distinctly see approach lights, runways, signs, markings, or other aspects of the external visual scene.

The optical performance of the HUD must not degrade, distort or detract from the pilot's view of external references or in regards to seeing and avoiding other aircraft such that it would not enable them to safely perform any maneuvers within the operating limits of the airplane (§25.773). Where the windshield optically modifies the pilot's view of the outside world, the conformal HUD symbols must be optically consistent with the perceived outside view. The combination of the windshield and the HUD must meet the requirements of § 25.773(a)(1).

The optical qualities of the HUD should be uniform across the entire field of view. When viewed by both eyes from any off-center position within the eyebox, non-uniformities shall not produce perceivable differences in binocular view. Additional guidance is provided in ARP 5288.

3.3 Crew Safety

Installation of HUD equipment brings into consideration potential physical hazards not traditionally associated with head down electronic flight deck displays.

The HUD system must be designed and installed to prevent the possibility of pilot injury in the event of an accident or any other foreseeable circumstance such as turbulence, hard landing, bird strike, etc. The installation of the HUD, including overhead unit and combiner, must comply with the head injury criteria (HIC) of § 25.562 (c)(5). Additionally, the HUD installation must comply with the retention requirements of § 25.789(a) and occupant injury requirements of §§ 25.785 (d) and (k).

For a dual HUD installation, there is the potential for both pilots to experience an incapacitating injury as a result of flight or gust loads. This becomes a safety of flight issue, since the entire flightcrew would be incapacitated. The types of injuries of concern may be long duration, low impact, high load, as opposed to the high impact, short duration injuries assessed by HIC. A dedicated method of compliance may be needed should analysis of the installation geometry indicate that flight or gust loads will produce occupant contact with the HUD installation.

For compliance to §§ 25.803, 25.1307, 25.1411 and 25.1447, the HUD installation must not interfere with or restrict the use of other installed equipment such as emergency oxygen masks, headsets, or microphones. The installation of the HUD must not adversely affect the emergency egress provisions for the flight crew, or significantly interfere with crew access. The system must not hinder the crew's movement while conducting any flight procedures.

3.4 HUD Controls

For compliance to § 25.777, the means of controlling the HUD, including its configuration and display modes, must be visible to, identifiable, accessible, and within the reach of, the pilots from their normal seated position. For compliance to §§ 25.777, 25.789 and 25.1301, the position and movement of the HUD controls must not lead to inadvertent operation. For compliance to § 25.1381, the HUD controls must be adequately illuminated for all normal ambient lighting conditions, and must not create any objectionable reflections on the HUD or other flight instruments. Unless a fixed level of illumination is satisfactory under all lighting conditions, there should be a means to control its intensity.

To the greatest extent practicable, the HUD controls should be integrated with other associated flight deck controls, to minimize the crew workload associated with HUD operation and to enable flightcrew awareness.

HUD controls, including the controls to change or select HUD modes, should be implemented to minimize pilot workload for data selection or data entry and allow the pilot to easily view and perform all mode control selections from his seated position.

4 INFORMATION PRESENTATION

4.1 Displayed Information

The HUD information display requirements will depend on the intended function of the HUD. Specific guidance for displayed information is contained within the main body and Appendix 1 of this AC. In addition, the following sections provide guidance related to unique characteristics of the HUD. As in the case of other flight deck displays, new and/or novel display formats may be subject to an Authority human factors pilot interface evaluation(s).

4.1.1 Alternate Formats of Displaying Primary Flight Information

There may be certain operations and phases of flight during which certain primary flight reference indications in the HUD do not need to have the analog cues for trend, deviation, and quick glance awareness that would normally be necessary. For example, during the precision approach phase, HUD formats have been accepted that provide a digital only display of airspeed and altitude. Acceptance of these displays has been predicated on the availability of compensating features that provide clear and distinct warning to the flight crew when these and certain other parameters exceed well-defined tolerances around the nominal approach state (e.g., approach warning), and these warnings have associated procedures that require the termination of the approach.

Formats with digital-only display of primary flight information (e.g., airspeed, altitude, attitude, heading) should be demonstrated to provide at least:

- a satisfactory level of task performance,
- a satisfactory awareness of proximity to limit values, like Vs, VMO and VFE, or
- a satisfactory means to avoid violating such limits.

If a different display format is used for go-around than that used for the approach, the format transition should occur automatically as a result of the normal go-around or missed approach procedure.

Changes in the display format and primary flight data arrangement should be minimized to prevent confusion and to enhance the pilots' ability to interpret vital data.

4.1.2 Aircraft Control Considerations

For those phases of flight where airworthiness approval is predicated on the use of the HUD, or when it can be reasonably expected that the pilot will operate primarily by reference to the HUD, the HUD should adequately provide:

- information to permit instant pilot evaluation of the airplane's flight state and position. This should be shown to be adequate for manually controlling the airplane, and for monitoring the performance of the automatic flight control system. Use of the HUD for manual control of the airplane and monitoring of the automatic flight control system, should not require exceptional skill, excessive workload, or excessive reference to other flight displays.

- cues for the pilot to instantly recognize unusual attitudes and shall not hinder its recovery. If the HUD is designed to provide guidance or information for recovery from upsets or unusual attitudes, recovery steering guidance commands should be distinct from, and not confused with, orientation symbology such as horizon "pointers." This capability should be shown for all foreseeable modes of upset, including crew mishandling, autopilot failure (including "slowovers"), and turbulence/gust encounters.

4.1.3 Airspeed Considerations

As with other electronic flight displays, the HUD airspeed indications may not typically show the entire range of airspeed. Section 25.1541 (b)(2) of the Federal Aviation Regulations states: "The airplane must contain - Any additional information, instrument markings, and placards required for the safe operation if there are unusual design, operating, or handling characteristics. "

Low speed awareness cues presented on the HUD should provide adequate visual cues to the pilot that the airspeed is below the reference operating speed for the airplane configuration (i.e., weight, flap setting, landing gear position, etc.); similarly, high speed awareness cues should provide adequate visual cues to the pilot that the airspeed is approaching an established upper limit that may result in a hazardous operating condition.

The cues should be readily distinguishable from other markings such as V-speeds and speed targets (bugs). The cues should not only indicate the boundary value of speed limit, but also clearly distinguish between the normal speed range and the unsafe speed range beyond those limiting values. Cross-hatching may be acceptable to provide delineation between zones of different meaning.

4.1.4 Flight Path Considerations

An indication of the aircraft's velocity vector, or flight path vector, is considered essential to most HUD applications. Earth-referenced flight path display information provides an instantaneous indication of where the aircraft is actually going. During an approach this information can be used to indicate the aircraft's impact or touchdown point on the runway. The earth referenced flight path will show the effects of wind on the motion of the airplane. The flight path vector can be used by the pilot to set a precise climb or dive angle relative to the conformal outside scene or relative to the HUD's flight path (pitch) reference scale and horizon displays. In the lateral axis the flight path symbols should indicate the aircraft track relative to the boresight.

Air mass derived flight path may be displayed as an alternative, but will not show the effects of wind on the motion of the airplane. In this case the lateral orientation of the flight path display represents the aircraft's sideslip while the vertical position relative to the reference symbol represents the aircraft's angle of attack.

The type of flight path information displayed (e.g., earth referenced, air mass) may be dependent on the operational characteristics of a particular aircraft and the phase of flight during which the flight path is to be displayed.

4.1.5 Attitude Considerations

An accurate, easy, quick glance interpretation of attitude by the pilot should be possible for all unusual attitude situations and command guidance display configurations. The pitch attitude display should be such that during all maneuvers a horizon reference remains visible with enough margin to allow the pilot to recognize pitch and roll orientation. For HUDs that are capable of displaying the horizon conformally, display of a non-conformal horizon reference should be distinctly different than the display of a conformal horizon reference.

In addition, extreme attitude symbology and automatically decluttering the HUD at extreme attitudes has been found acceptable (extreme attitude symbology should not be visible during normal maneuvering).

When the HUD is designed not to be used for recovery from unusual attitude, there should be:

- compensating features (e.g., characteristics of the airplane and the HUD system),
- immediate direction to the pilot to use the head down PFD for recovery, and
- satisfactory demonstration of timely recognition and correct recovery maneuvers.

4.2 Display Compatibility

The content, arrangement and format of the HUD information should be sufficiently compatible and consistent with the head down displays to preclude pilot confusion, misinterpretation, or excessive cognitive workload. Transitions between the HUD and head down displays, whether required by navigation duties, failure conditions, unusual airplane attitudes, or other reasons, should not present difficulties in data interpretation or delays/interruptions in the flight crew's ability to manually control the airplane or to monitor the automatic flight control system.

The HUD and HDD formats and data sources need to be compatible to ensure that the same information presented on both displays have the same intended meaning. HUD and HDD parameters should be consistent to avoid misinterpretation of similar information, but the display presentations need not be identical.

Deviation from these guidelines may be unavoidable due to conflict with other information display characteristics or requirements unique to head up displays. These may include minimization of display clutter, minimization of excessive symbol flashing, and the presentation of certain information conformal to the outside scene. Deviations from these guidelines will require additional pilot evaluation.

The following should be considered:

(a) Symbols that have the same meaning should be the same format;

(b) Information (symbols) should appear in the same general location relative to other information;

(c) Alphanumeric readouts should have the same resolution, units, and labeling (e.g., the command reference indication for "vertical speed" should be displayed in the same foot-per-minute increments and labeled with the same characters as the head-down displays);

(d) Analogue scales or dials should have the same range and dynamic operation (e.g., a Glideslope Deviation Scale displayed head-up should have the same displayed range as the Glideslope Deviation Scale displayed head-down, and the direction of movement should be consistent);

(e) FGS modes (e.g. autopilot, flight director, autothrust) and state transitions (e.g. land 2 to land 3) should be displayed on the HUD, and except for the use of colour, should be displayed using consistent methods (e.g., the method used head-down to indicate a flight director mode transitioning from armed to captured should also be used head-up); and

(f) Information sources should be consistent between the HUD and the head-down displays used by the same pilot.

(g) When command information (i.e., flight director commands) is displayed on the HUD in addition to the head-down displays, the HUD depiction and guidance cue deviation "scaling" needs to be consistent with that used on the head-down displays. This is intended to provide comparable pilot performance and workload when using either head-up or head-down displays.

(h) The unique information concerning current HUD system mode, reference data, status state transitions, and alert information that is displayed to the pilot flying on the HUD, should also be displayed to the pilot not flying using consistent nomenclature to ensure unambiguous awareness of the HUD operation.

4.3 Indications and Alerts

In order to demonstrate compliance with 25.1322 and to the extent that most HUDs are currently single color (monochrome) devices, caution and warning information should be emphasized with the appropriate use of attention-getting properties such as flashing, outline boxes, brightness, size, and/or location to compensate for the lack of color coding. A consistent documented philosophy should be developed for each alert level and conflicts of meaning with head-down display format changes will need to be avoided.

Additional guidance is in AC 25.1329 and AC 25.1322 and the associated regulations.

4.4 Display Clutter

Clutter has been addressed elsewhere in this A(M)C. However, for a HUD, special attention is needed regarding the effects of clutter affecting the see-through characteristics of the display.

5 VISUAL CHARACTERISTICS

The following paragraphs highlight some areas, which are related to performance aspects that are specific to the HUD. ARP5288 and AS8055 provide performance guidelines for a head-up display. As stated in Chapter 3, the applicant should notify the Airworthiness Authority if any visual display characteristics do not meet the guidelines in AS8055 and ARP 5288.

5.1 Luminance Control

The display luminance (brightness) should be satisfactory in the presence of dynamically changing background (ambient) lighting conditions (0 to 10,000 fL per AS8055), so that the HUD data is visible to the pilot(s). To accomplish this, the HUD may have both manual and automatic luminance control capabilities. It is recommended that automatic control is provided in addition to the manual control. Manual control of the HUD brightness level should be available to the flight crew in order to provide the means to set a reference level for automatic brightness control. If automatic control for display brightness is not provided, it should be shown that a single manual setting is satisfactory for the range of lighting conditions encountered during all foreseeable operational conditions and against expected external scenes. Readability of the displays should be satisfactory in all foreseeable operating and ambient lighting conditions. AS8055 and ARP 5288 provide guidelines for contrast and luminance control.

5.2 Alignment

Proper HUD alignment is needed to match conformal display parameters as close as possible to the outside (real) world, depending on the intended function of those parameters.

If the HUD combiner is stowable, means should be provided to ensure that it is fully deployed prior to using the symbology for aircraft control. The HUD system shall provide means to alert the pilot if the position of the combiner causes normally conformal data to become misaligned in a manner that may result in display of misleading information.

The range of motion of conformal symbology can present certain challenges in rapidly changing and high crosswind conditions. In certain cases, the motion of the guidance and the primary reference cue may be limited by the field of view.

It should be shown that, in such cases, the guidance remains usable and that there is a positive indication that it is no longer conformal with the outside scene. It should also be shown that there is no interference between the indications of primary flight information and the flight guidance cues.

5.2.1 Symbol Positioning Accuracy (External)

External Symbol Positioning Accuracy, or Display Accuracy, is a measure of the relative conformality of the HUD display with respect to the real world view seen by the pilot through the combiner and windshield from any eye position within the HUD Eyebox. Display Accuracy is a monocular measurement, and, for a fixed field point, is numerically equal to the angular difference between the position of a real world feature as seen through the combiner and windshield, and the HUD projected symbology.

The total HUD system display accuracy error budget (excluding sensor and windshield errors) includes installation errors, digitization errors, electronic gain and offset errors, optical errors, combiner positioning errors, errors associated with the CRT and yoke (if applicable), misalignment errors, environmental conditions (i.e., temperature and vibration), and component variations. Optical errors are both head position and field angle dependent and are comprised of three sources: uncompensated pupil and field errors originating in the optical system aberrations, image distortion errors, and manufacturing variations. The optical errors are statistically determined by sampling the HUD FOV and Eyebox. (See 4.2.10 of SAE 8055 for a discussion of field of view and Eyebox sampling);

- The optical errors shall represent 95.4% (2 sigma) of all sampled points.
- The display accuracy errors are characterized in both the horizontal and vertical planes.
- Total display accuracy shall be characterized as the root-sum square (RSS) errors of these two component errors.

All display errors shall be minimized across the display field of view consistent with the intended function of the HUD. The following are the allowable display accuracy errors for a conformal HUD as measured from the HUD Eye Reference Point:

- HUD Boresight <= 5.0 mrad
- <= 10° diameter <= 7.5 mrad (2 Sigma)
- <= 30° diameter <=10.0 mrad (2 Sigma)
- >30° diameter < 10 mrad + kr[(FOV)(in degrees) - 30)] (2 Sigma)
  kr = 0.2 mrad of error per degree of FOV

The HUD manufacturer shall specify the maximum allowable installation error. In no case shall the display accuracy error tolerances cause hazardously misleading data to be presented to the pilot viewing the HUD.

5.2.2 Symbol Positioning Alignment

Symbols which are interpreted relative to each other shall be aligned to preclude erroneous interpretation of information. Symbols which are not interpreted relative to each other may overlap but shall not cause erroneous interpretation of display data, even when they overlap.

5.2.3 Combiner Position Alignment:

The HUD system shall provide a warning to the pilot if the position of the combiner causes conformal data to become hazardously misaligned.

5.3 Reflections and Glare

The HUD must be free of glare and reflections that could interfere with the normal duties of the minimum flight crew (per 14 CFR 25.1523 and 25.777).

5.4 Ghost Images

The visibility of ghost images within the HUD of external surfaces must be minimized so as not to impair the pilot's ability to use the display.

A ghost image is an undesired image appearing at the image plane of an optical system. Reflected light may form an image near the plane of the primary image. This may result in a false image of the object or an out-of-focus image of a bright source of light in the field of the optical system (e.g., a "ghost image").

5.5 Design Eye Position

The HUD Design Eye Position (DEP) must be the same as that defined for the basic cockpit in accordance with AC 25.773-1. The Design Eyebox must contain the DEP. The displayed symbols which are necessary to perform the required tasks must be visible to the pilot from the DEP and the symbols must be positioned such that excessive eye movements are not required to scan elements of the display.

5.6 Field Of View

The Field of View should be established by taking into consideration the intended operational environment and potential aircraft configurations.

5.7 Head Motion

The visibility of the displayed symbols must not be unduly sensitive to pilot head movements in all expected flight conditions. In the event of a total loss of the display as a result of a head movement, the pilot must be able to regain the display rapidly and without difficulty.

5.8 Accuracy and Stability

The system operation should not be adversely affected by aircraft manoeuvring or changes in attitude encountered in normal service.
The accuracy of positioning of symbols must be commensurate with their intended use. Motion of non-conformal symbols must be smooth, not sluggish or jerky, and consistent with aircraft control response. Symbols must be stable with no discernible flicker or jitter.

5.9 HUD Optical Performance

As far as practicable, the optical performance of the HUD must not degrade, distort or detract from the pilot's view of external references or of other aircraft. Where the windshield optically modifies the pilot's view of the outside world, the conformal HUD symbols must be optically consistent with the perceived outside view. The combination of the windshield and the HUD must meet the requirements of 14 CFR/CS 25.773(a)(1).

6 SAFETY ASPECTS

The installation of HUD systems in flight decks may introduce complex functional interrelationships between the pilots and other display and control systems. Consequently, a Functional Hazard Assessment (FHA) which requires a top down approach, from an airplane level perspective, should be developed in accordance with FAR/CS 25.1309. Development of a FHA for a particular installation requires careful consideration of the role the HUD plays within the flight deck in terms of integrity of function and availability of function, as well the operational concept of the installation to be certified (dual vs single, type and amount of information displayed, etc.). Chapter 4 of this AC provides material that may be useful in supporting the FHA preparation.

All alleviating flight crew actions that are considered in the HUD safety analysis need to be validated for incorporation in the airplane flight manual procedures section or for inclusion in type-specific training.

Since the flight information displayed on the HUD is visible only to one pilot, and since in most cases, failures of flight parameters shown on the HUD are not independent of those shown on the same pilot's head down primary flight display, the *applicant should demonstrate that* the HUD only provides a suitable means to comply with 25.1333(b) following loss of primary head down flight display to the pilot using the HUD. The rule requires that at least one display of information essential to safety of flight remain available to the (both) pilots, not just one pilot.

7 CONTINUED AIRWORTHINESS

Deleted: Since the flight information displayed on the HUD is visible only to one pilot, and since in most cases, failures of flight parameters shown on the HUD are not independent of those shown on the same pilot's head down primary flight display, the HUD may not be a suitable means to comply with 25.1333(b) following loss of primary head down flight displays. The rule requires that at least one display of information essential to safety of flight remain available to the (both) pilots, not just one pilot. ¶

Depending on the type of operation and the intended function of the HUD, instructions for the continued airworthiness of a display system and its components have to be prepared to show compliance with §§ 25.1309 and 25.1529 (including Appendix H)

8 FLIGHT DATA RECORDING

The installation of HUDs has design aspects and unique operational characteristics requiring specific accident recording considerations. HUD guidance modes and status (in use or inoperative) and display declutter mode should be considered to be recorded to comply with § 25.1459(e) and 121.344.